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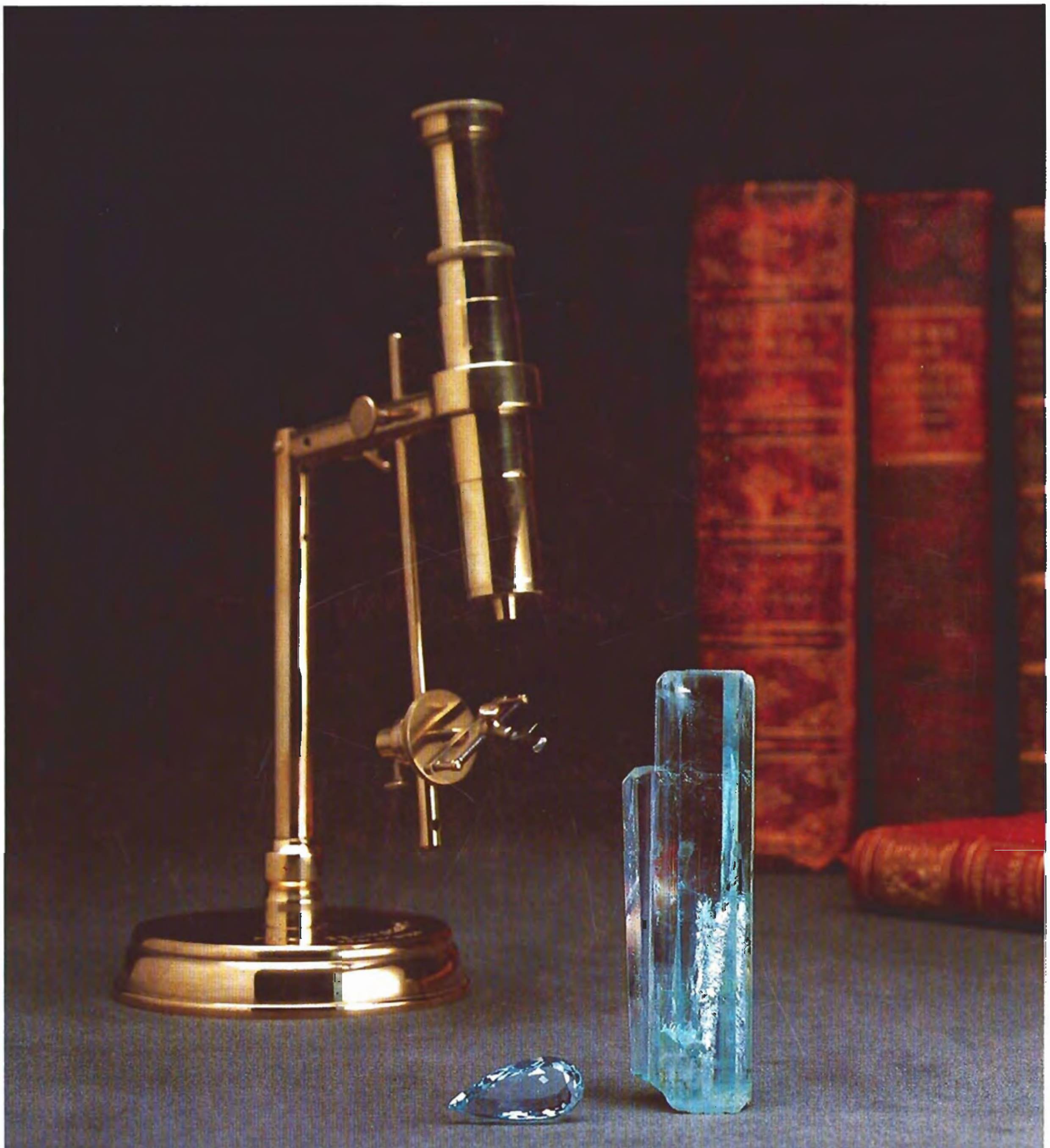

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Gems & Gemology

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ABOUT THE COVER: The elements of gemology are summed up in this classic pose: microscope, books, faceted stone (in this case, a 32.21 ct. aquamarine), and natural crystal (here, an aquamarine from Afghanistan, courtesy of the Los Angeles County Museum of Natural History, Los Angeles, CA). Cover design by Peter Johnston, photography by Michael Havstad.

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AN INTRODUCTION TO THE NEW GEMS & GEMOLOGY

RICHARD T. LIDDICOAT, Jr. Editor-in-Chief

Commencing with this, the first issue of the 17th volume of *Gems & Gemology,* the quarterly publication of the Gemological Institute of America has a new look, new size, and a commitment to become the most comprehensive periodical in the field of gemology. It seems fitting that this dramatic change will be effected during the 50th anniversary celebration of the founding of GIA by Robert M. Shipley in 1931.

Since its inception in 1934, *Gems & Gemology* traditionally has followed a 6″ × 9″ format and almost always in 32 pages. Over the years, color has been used only sparingly.

During these years, however, the jewelry industry has expanded rapidly and become increasingly sophisticated and well-educated. GIA is acutely aware of the greater need and desire of this industry and others involved in the field to be well-informed about new materials, new techniques, and other developments in gemology.

With the new *Gems & Gemology,* we have increased the size of the journal almost four-fold—to 8½″ × 11″, with a minimum of 64 pages per issue. Recognizing the integral role that color plays in dealing with gem materials, we have used color photographs throughout where possible. Perhaps most important, to help ensure the accuracy and usefulness of the papers published we have called upon many of the prominent figures in the gemological community to serve on the journal's Editorial Review Board. All manuscripts submitted to *Gems & Gemology* now are reviewed by at least two members of the board in addition to the associate editors, Peter Keller and Vince Manson, and me. Only the meaningful articles will be published.

Other editorial innovations have been made to increase the usefulness of this quarterly publication. With news from Robert Crowningshield, Karin Hurwit, and Robert Kane, section editor Chuck Fryer has expanded and reorganized the Lab Notes column. GIA librarian Dona Dirlam, with the help of her large review board, has designed the Gemological Abstracts section to serve as the most comprehensive review available of articles relating to gemology. In addition to English publications, magazines in German, French, Spanish, Portuguese, and Japanese will be screened and abstracted on a regular basis. John Koivula will continue to provide a similar service for books in the field, and Stephanie Dillon will strive to present the latest information on current happenings in the gem world.

As the journal of the Gemological Institute of America, *Gems & Gemology* will cover not only topics directly related to gems, but also those concerning jewelry arts, including design and manufacturing, as well as subjects related to the management of jewelry enterprises.

Authors seeking publication of papers on any subject matter in the fields outlined above are encouraged to submit manuscripts to *Gems & Gemology.* Letters on articles published in the journal and other topics important to the industry also are welcome.

It is the intention of the staff of *Gems & Gemology* to provide gemologists and gem enthusiasts everywhere with the latest developments and most comprehensive coverage in the field.

ZABARGAD: THE ANCIENT PERIDOT ISLAND IN THE RED SEA

By Edward Gübelin

***R**eflecting on his 1980 visit to Zabargad, the author provides an update on this relatively unknown island and the beautiful peridots for which it has gained fame. He complements his discussion of the geology of Zabargad, the peridot occurrences, the mining techniques, and the characteristics of the gemstone with a look at the ancient history of the island and the etymological changes surrounding the stone's current name,* peridot. *Although somewhat low on the hardness scale, this magnificent gemstone has regained popular appreciation, and the crystals from Zabargad are still among the finest in the world.*

ABOUT THE AUTHOR

Dr. Gübelin is a gemologist and honorary professor at the University of Stellenbosch, Switzerland.

Acknowledgments: The author extends his genuine thanks to Professor Dr. Max Weibel of the Institute for Crystallography and Petrography of the University of Zurich for his reading of the manuscript and his helpful commentary. Many appreciative thanks also to Dr. P. Bancroft of Fallbrook, California, who arranged the excursion and was an excellent companion.

Zabargad is the oldest and longest-known source of gem peridots (fig. 1); yet the island, just as much as the gemstone it hoarded, has slid repeatedly into oblivion, only to be rediscovered over and over again and forgotten once more. The author visited this tiny island in the Red Sea in March of 1980. Located about 60 miles southeast of the Râs Banâs peninsula, at 23° 36′ 16″ N and 36° 11′ 42″ E (fig. 2), it is situated 16 km north of the Tropic of Cancer. Zabargad is only 3.2 km long and 2.4 km wide, covering an area of 4.5 km^2. There is hardly any life on the island and no fresh water at all; one may justly describe it as a "desert island." In fact, apart from low-growing shrubs, several giant turtles, and a few birds such as wagtails, ospreys, and gulls, practically no flora or fauna exist on Zabargad. The highest ground is the so-called Peridot Hill (235 m above sea level), which together with some smaller hills (135 m above sea level) forms the most impressive sight that the island offers the approaching seafarer (fig. 3). Despite the lack of vegetation, the island is at its most beautiful when the yellow to dark brown tones of the various rocks and dump-heaps before the many pits brighten in the light of the morning sun. The adventurer with any imagination at all cannot avoid letting the pageant of history unfold (see box).

REGIONAL GEOLOGY

The occurrence of peridot on Zabargad is intimately related to the regional geology and the tectonic processes that on a larger scale were responsible for the formation of the Red Sea itself. As an extension of the East African Rift Valley and part of the global rift system, the Red Sea is a geologically young feature that evolved in the Tertiary period of geologic time, 65 to 13 million years ago.

The rocks seen on the island represent the results of magmatic activity with associated metamorphism of preexisting sediments and were all exposed through tec-

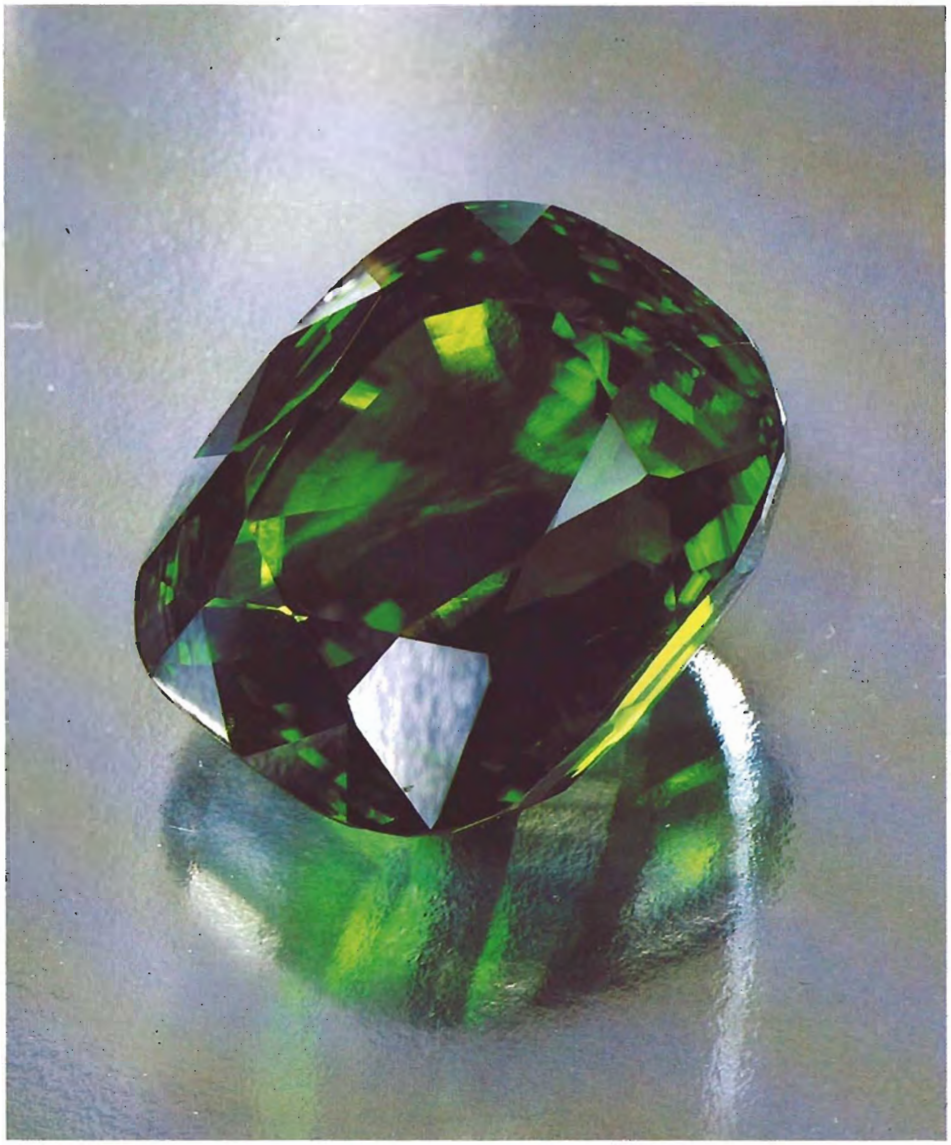

Figure 1. Faceted peridot from Zabargad, 284.85 carats (property of Messrs. A. Ruppenthal, Idar-Oberstein, Germany).

tonic uplift and erosion. Mafic igneous rocks (Badgley, 1965), which represent the bulk of the island, are of deep-seated origin. They are notable for their low silica content and consist primarily of lherzolites, characterized by abundant olivine, pyroxene, and amphibole. The metamorphic rocks, in turn, consist of serpentinites, granulites, schists, and slates. The alluvial sediments and an extensive gypsum deposit are of more recent origin.

The topography of the island reflects its tectonic history. The terrain is extremely irregular, the coastline consisting of fractured escarpment terraces. Numerous coral banks and reefs occur in the surrounding waters.

THE PERIDOT OCCURRENCES

No detailed documentation of the peridot occurrences on Zabargad has been made. An interesting review of available information is provided by Wilson (1976).

It seems likely that peridots were once found on several parts of the island—in fact, almost everywhere the peridotites outcrop. The finest and largest gem crystals, it is believed, occurred in such quantitites on the eastern slopes of Peridot Hill that mining was worthwhile. Here they appear to have been recovered in vein-like areas of the serpentinized peridotite. The tiny veins run in all directions so that in places they form

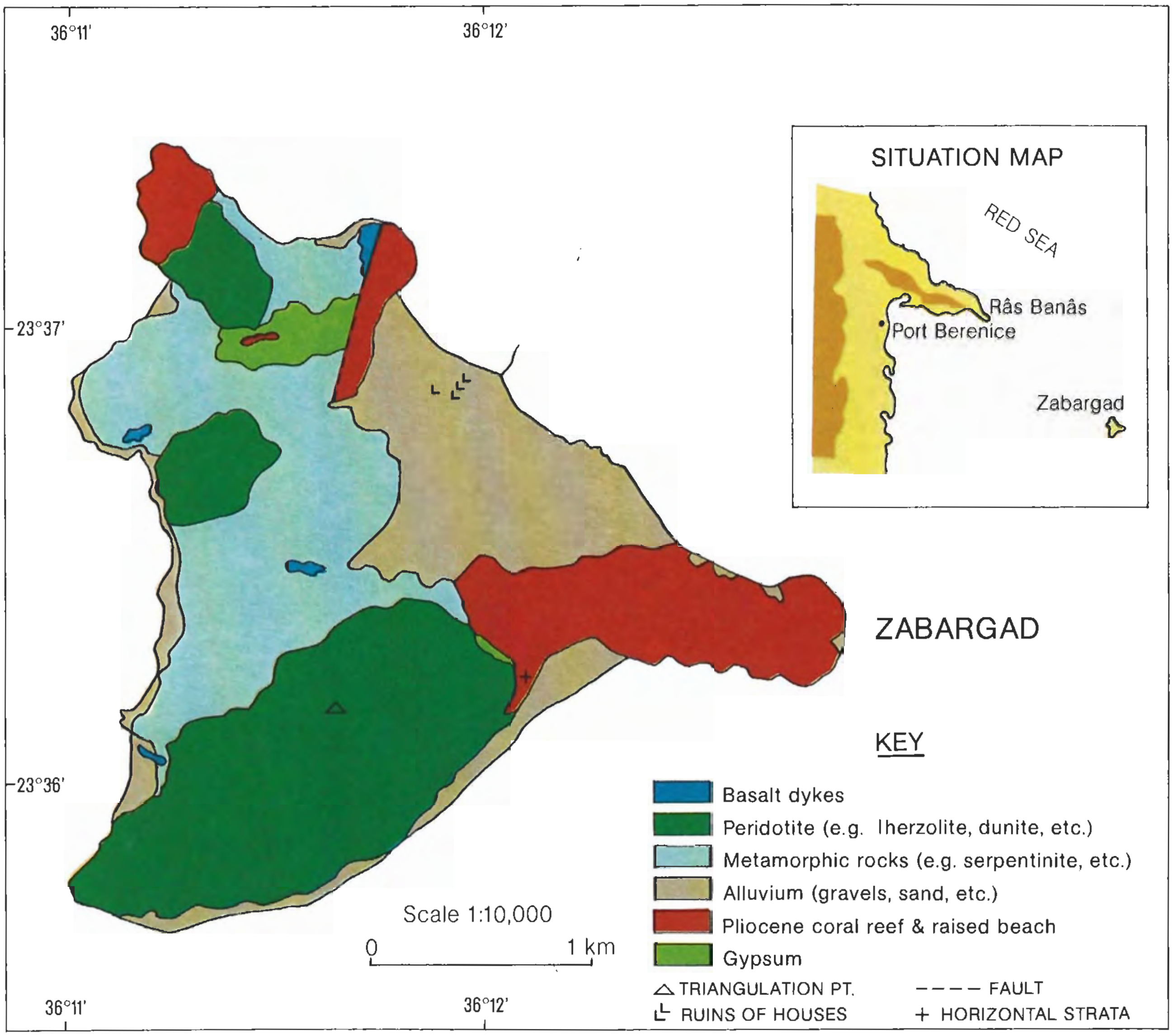

Figure 2. Geologic map of the island of Zabargad. Inset shows the relationship of the island to the Egyptian mainland.

an actual stockwork that occupies an oval region of considerable extent.

The peridot crystals must originally have followed and lined open cracks and fissures, inasmuch as they were probably formed on the walls of fractures. As a result of tectonic movements, they were later broken from their original sites and included among the rubble of the cracks. In this author's view, however, this theory is only valid if the transformation of the peridotite into serpentinite occurred metasomatically and before or during the formation of the peridot crystals; otherwise they too would have undergone serpentinization. Since the crystals are absolutely fresh and well preserved, or at the most very slightly etched, they must have developed at the same time or at a later stage. However, unless and until the island is investigated in its entirety mineralogically and petrographically, such ideas must remain speculations.

Shortly before the visit of the author and his companion, a joint American-Austrian expedition consisting of curators from the Vienna Museum of Natural History and the American Museum of Natural History in cooperation with the Egyptian Geological Survey, and with the help of the El Nasr Phosphate Company, spent several days on the island. It is to be hoped that new and valid knowledge can be expected from these investigators. At the old sieving places (fig.

Figure 3. View of Peridot Hill, the highest point on the island (235 m above sea level), as seen from the northeast. Note the dump-heaps at the foot of the hill.

Figure 4. Sieving place in the foreground and dump-heaps in the background on the eastern slope of Peridot Hill.

4), in the prematurely abandoned sieve-heaps, and among the waste of the mines, the author and his companion found over a hundred fresh, transparent, well-preserved, in part broken but certainly cutable peridot crystals pale yellowish green to deep olive green in color. Conspicuous samples of the macroscopic paragenesis of these peridot crystals were green garnierite and fresh whitish to weathered grey cancrinite. The peridot crystals, pseudohexagonal after b(010) in form, were between 5 and 15 mm along the a-axis. Formerly, however, one could find peridot crystals up to 10 cm long, although those 2–4 cm in length were much more abundant. The Geological Museum in London owns a splendid step-cut peridot of 146 ct., while the largest known cut peridot weighs 310 ct. and is exhibited at the Smithsonian Institution in Washington, DC. Both of these magnificent samples came originally from the island of Zabargad.

MINING

The original mining methods consisted of primitive manual digging, whereby each individual vein was excavated (fig. 5). The miners worked

Figure 5. Low tunnel dug into metamorphic rock to reach the deeper mafic rock (note the white bands of magnesite).

FROM "TOPAZOS" TO PERIDOT: ZABARGAD AND ITS GEM SHARE A PLACE IN HISTORY, LANGUAGE, AND LORE

Topazios is the name used by Greek author Alexander Polyhistor to refer to an island on which gemstones are found whose color "resembles that of fresh oil." The great naturalist of ancient times, Pliny the Elder (23–79 A.D.), mentions the island "Topazios" in his work *Naturalis Historia.* He refers specifically to King Juba II of Mauretania (25 B.C.–23 A.D.) who reportedly states in his writings that this legendary island in the Red Sea was first explored during the reign of Queen Berenice (340–279 B.C.). Pliny also refers to another report that pirates driven by adverse winds landed on an island in the Red Sea called Chytis or Cytis. Being in a famished condition, they sought herbs and roots in the ground and thereby found the first "topazos." Other names attributed to the island in ancient times include Island of Death (Nekron) and Ophiodes ("snake island," reported by Agatharchides of Knidos, 181–146 B.C.). Not until the time of the Crusades did this mystery-bound scrap of land receive the name by which it is still mistakenly known in the West, St. John's Island, and finally, Zabargad.

For Pliny the Elder, *topazos* was a jewel that mainly occurs in green but may also be yellow. Probably there is some confusion here with chrysolite, "chrysolithos," which was also known in ancient times (Ezekiel 10, 9). During the period, *chrysos* meant golden, that is, yellow. Not until much later did the word experience an etymological change as the prefix *chryso-* entered common usage to describe a green stone (see chrysoberyl, chrysoprase, chrysopal, chrysocolla, chrysolite, etc.).

When in the early 18th century the name *topaz* was finally affixed to the fluorine-bearing aluminum silicate that currently holds this title, a new name was needed for the green gemstone from Zabargad. In 1790, the sometime mineralogist A. G. Werner named the mineral olivine because of its typical olive-green color. In the same year, he published a description of chrysolite in *Bergmanns Journal* 3, stating that it was a mineral in its own right. A few years later, M. H. Klaproth was able to prove that olivine and chrysolite belong to the same family of minerals. Although *chrysolite* was used by German and American mineralogists for over 100 years, this term has left general usage and is no longer accepted in English nomenclature for the gemstone. The English adopted Werner's name *olivine,* while the French gave preference to the new name *peridot,* which is derived from the Arabian word *faridat,* meaning gem. The latter is generally used today to refer to the gemstone, whereas the true name of the mineral is olivine (see Ball, 1950, Lüschen, 1979, and Mitchel, 1979, for further information on the various names).

Archaeological excavations in Alexandria have apparently unearthed valuable peridots. Faceted samples, which could only have come from Zabargad, have also been discovered in ancient Greece. In all probability, the fabulous stone that once adorned King Ezekiel from Tyrus (about 586 B.C.; Ezekiel 28, 13) was a peridot from Zabargad. Where so much treasure and beauty were to be found, the authorities kept a wary eye. Diodorus Siculus writes in the first century before Christ: "The Egyptians kept the island under constant watch, and anyone who tried to approach the treasure island without permission—let alone to attempt to land and steal the peridots—was threatened with death." Thus, this island in the Red Sea became one of the most closely guarded regions of the ancient world, and its treasure was held secret for centuries, virtually hidden from the Western world from biblical times until the onset of the baroque period in the 17th century.

Figure 6. Peridot crystal on its original matrix, self-collected by the author. The crystal is approximately 1.2 cm × 1.1 cm.

downwards until the vein, usually at a shallow depth, became sterile or contracted. However, the peridots were not found where they had crystallized. They were always loosely attached to the walls of the veinlets and could easily be removed from their position. Wilson (1976) noted that he knew of no peridot crystal that he could in good conscience claim was found directly grown on its mother-rock. However, the author of this present article was so lucky as to find a piece of matrix about the size of a child's fist with a fully grown, well-developed peridot crystal attached (fig. 6).

During the years before World War I, from about 1906 onwards, the island of Zabargad was generally known as *the* source of peridot, and mining rights were monopolized by the Khedive, the Turkish viceroy in Egypt. Within a four-year period, more than $2 million in peridot (present day value) was found and sent to France for cutting. The chief problem on the island then, as now, was the lack of fresh drinking water for the miners. The mining company overcame this difficulty by erecting a large gasoline-powered water condenser (of which a few rusty parts are still lying around today). In 1922 the Egyptian government gave the mining rights to the Red Sea Mining Company. In the years that followed, until the outbreak of World War II, this company brought out a considerable amount of peridot. In 1958, the deposits were nationalized by Egyptian President G. A. Nasser.

DESCRIPTION AND PROPERTIES

Gem peridot lies compositionally between the end members forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4) of the olivine isomorphous series $(Mg, Fe)_2[SiO_4]$, in which the two divalent cations Mg and Fe can replace each other diadochally. The peridots from Zabargad contain 8%–10% FeO (FeO + MgO amount to approximately 64%; Wilson, 1976). The crystals are elongated along the a-axis so that the brachy pinacoid b(010), which is markedly striated vertically to the c-axis, forms the largest face. The gradations in color of this summer-green gemstone (the birthstone for August), as well as the variations in its other physical properties, are caused by the iron content (see Troeger, 1956, p. 54) and other components. The color tones of the finest qualities correspond with the DIN color chart 6164, page 24, colors 24:6:2;24:6:3 to 24:6:4 of the color norms X_c34.2; Y_c43.7; Z_c10.2 or X_c23.0; Y_c29.4; Z_c6.9 or X_c15.2; Y_c19.5, and Z_c4.6. Refractive indices vary little, from 1.650 to 1.654 for $n\alpha$ and between 1.686 and 1.690 for $n\gamma$, with a constant value for $n\beta$ only a little below the middle of the two extreme readings. The high birefringence remains constant at 0.036, as does the density (3.34) which is only 0.01 above that of pure methylene iodide, in which liquid peridot remains suspended or sinks slowly. Pleochroism is weak but perceptible as pale green along α, green along β, and light green along γ. The absorption spectrum reveals the iron content by means of three characteristically placed bands in the blue to blue-green region at 453, 473, and 493 nm.

Diagnostically important are the rounded plate-like and wafer-thin healing seams or residual drops, in the approximate center of which a black grain of chromite is situated. Their appearance may be likened to that of a water-lily leaf, and they are consequently termed "lily pads."

CONCLUSION

Since mining on Zabargad has failed to remain lucrative, other sources have filled the demand for peridot. Relatively great numbers of large, attractive peridots from Kyaukpon, above Mogok in Burma are still reaching the market. Today's second largest supplier of cutable gem peridots is near San Carlos, in Arizona, followed up by a deposit at Söndmöre in Norway, which produces peridots that are slightly lighter in color and very brilliant when faceted. In addition, some small fragments of peridot are said to come from Hawaii.

Despite its somewhat low hardness of 6½–7 (lying just below the critical border of gemstone hardness, 7), this magnificent gemstone with its agreeable sparkle and its glimmer like damp moss in the evening sunlight, has today once more gained appreciation and popularity.

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CUBIC ZIRCONIA: AN UPDATE

By Kurt Nassau

Soon after it was first marketed in 1976, colorless cubic zirconia became the dominant diamond imitation, with current production of approximately 60 million carats per year. Although cubic zirconia was discovered as a natural mineral in 1937, crystals usable for faceting were first produced in 1969 and it was not until a practical skull-melting technique was developed in the USSR in 1972 that commercial production became feasible. This article reviews the skull-melting technique used to produce cubic zirconia and examines the current status of this diamond simulant with regard to quality, production, and market. The patent situation is discussed, as well as prospects for new diamond imitations and the recent surge of interest in colored cubic zirconia. Also included is an Appendix summarizing the technical and gemological data for cubic zirconia and its distinguishing characteristics.

ABOUT THE AUTHOR

Dr. Nassau is a research scientist residing in Bernardsville, NJ.

Cubic zirconia was discovered as a natural mineral in 1937, when two German mineralogists, von Stackelberg and Chudoba (1937), were examining a highly metamict zircon given to them by B. W. Anderson. The zircon contained some tiny crystals which they identified by X-ray diffraction as the cubic form of zirconium oxide (or zirconia), a compound known as baddeleyite when in the monoclinic form. So little did von Stackelberg and Chudoba think of this discovery that they did not even assign a name to the new mineral. As a result, it is known to this day by its scientific name, *cubic zirconia,* and the prefix *synthetic,* although proper, is not usually included.

This same material had already been used for many years as a ceramic composition for high-temperature industrial and scientific purposes; because of an exceptionally high melting point, "stabilized zirconia" ceramics can be used at temperatures up to 2540°C (4604°F) and are very resistant to most chemical substances. Such stabilized zirconia typically consists of 96% ZrO_2 (zirconia) and 4% CaO (lime), although MgO (magnesia) or Y_2O_3 (yttria) also can be used in place of the CaO. Further discussion of the early work on this material is given in Nassau (1977).

Whenever the powder or ceramic form of a substance has interesting properties, scientists usually attempt to grow large crystals; this permits a more precise study of a broader range of properties and often leads to additional uses. In the case of cubic zirconia, crystal growth proved most difficult in view of the material's exceptionally high melting point. Pure ZrO_2 melts at about 2750°C (4982°F), but at a somewhat lower temperature when stabilizers are added. Flux growth was tried (Nassau, 1977, 1980a), but it produced either monoclinic baddeleyite or a tetragonal form. On heating, the former is transformed from monoclinic to tetragonal at about 1100°C (2012°F), and from tetragonal to cubic at about 2000°C (3632°F). Un-

Figure 1. A large skull-melting apparatus being operated by George Bramhall. Courtesy of the Ceres Corp., Waltham, MA.

fortunately, these changes reverse on cooling and the starting material forms once again. The addition of stabilizers such as CaO, MgO, or Y_2O_3 prevents these transformations on cooling: cubic zirconia then remains the stable form down to room temperature. Details of the different forms of zirconia are given in the Appendix.

Crystals of cubic zirconia in a usable size were finally reported in 1969 by Roulin, Vitter, and Déportes of France. They used a difficult form of melting the material without a crucible to obtain crystals more than 15 mm (0.6 inch) long, of composition 87.5% ZrO_2, 12.5% Y_2O_3. Only a few properties of the crystals appear to have been measured at that time, however, and the potential remained unrecognized. A somewhat modified and greatly enlarged form of this apparatus was used by Aleksandrov, Osiko, Prokhorov, and Tatarintsev at the Lebedev Physical Institute of the USSR Academy of Sciences in Moscow (1973).

Their technique, called "skull melting," is described in detail in the next section. Crystals one inch (2.5 cm) and larger in diameter can be grown with a modern embodiment of this arrangement (fig. 1) without excessive difficulty. The impetus for this work had been the hope—unfulfilled—of finding improved materials for laser or opto-electronic uses, but measurements of the crystals showed a material that was hard, colorless, and with optical properties that approximate the brilliance and fire of diamond better than any previous diamond imitation.

With its introduction into the gem trade late in 1976, cubic zirconia as a diamond imitation immediately created a huge demand as well as considerable anxiety. As with the introduction of every diamond imitation before it (Nassau, 1980a), some jewelers who did not know how to recognize the new material were unable to protect themselves. Nevertheless, examination techniques have now been adapted to readily distinguish cubic zirconia from diamond, and new instruments have appeared to assist the gemologist-jeweler in this task, as outlined in the Appendix.

As with YAG (yttrium aluminum garnet), which was overproduced and peaked about 1972 (Nassau, 1980a), we are now seeing a rapid rise in the production of cubic zirconia accompanied by a rapid fall in the price. This supply-and-demand movement, together with the recent introduction of colored forms of cubic zirconia and the curious patent situation, is also discussed in the following sections.

THE SKULL-MELTING TECHNIQUE FOR GROWING CUBIC ZIRCONIA

The technique of crystal growth by solidification from the melt in a container is one of the easiest and least costly ways of obtaining large crystals. When, however, a material has as high a melting point and is as reactive as cubic zirconia, no container can be found to hold the melt, and a "self-contained melt," "cold crucible," or "autocrucible" arrangement must be used. The technique described here was patented by Joseph F. Wenckus and coworkers (1977), now one of the major manufacturers of cubic zirconia as the Ceres Corporation, Waltham, MA.

The apparatus shown in figures 2 and 3 consists of a cup-like arrangement made up of a circle of copper fingers, water-cooled by complicated in-

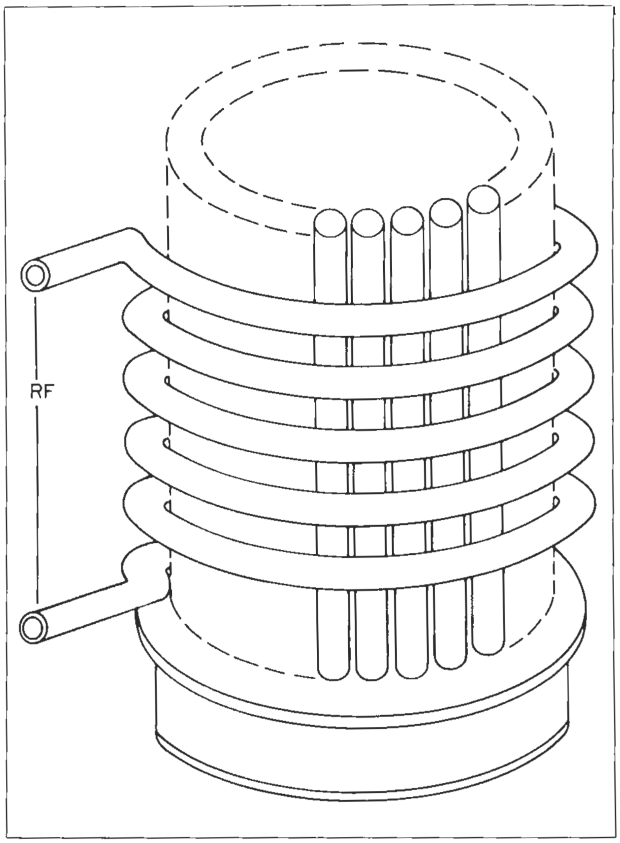

Figure 2. Schematic of one form of skull-melting apparatus; only some of the fingers are shown.

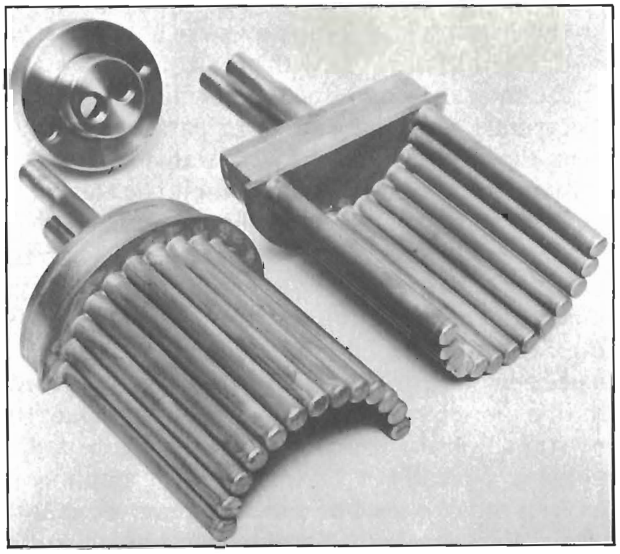

Figure 3. The split halves of a small skull-melting apparatus.

ternal plumbing. There are small gaps between the fingers. Surrounding this apparatus is a water-cooled copper coil activated by a radio-frequency generator, typically operated at a frequency of 4 MHz and at power levels as high as 100 kW.

The small gaps between the metal fingers enable the radio-frequency energy to pass into the cup, which is initially filled with zirconia powder mixed with the required stabilizer. The powder is an electrical insulator at room temperature; it will not begin to heat until after the addition of some pieces of zirconium metal, which are then rapidly heated by the radio-frequency field. As the zirconia adjacent to the zirconium metal heats up, it also begins to conduct electricity and melts in a matter of minutes. The zirconium metal reacts with the oxygen in the air to produce more zirconia.

All the zirconia soon melts, except for a relatively thin sintered shell or skin that remains solid because it is cooled and prevented from melting by contact with the water-cooled fingers. In this way the molten zirconia is contained within a jacket of its own powder, which also prevents contamination from the metal. More zirconia, again containing the required stabilizer, is added to the molten material to fill the skull to the desired level. A porous crust forms over the top of the melt, as shown in section A of figure 4, and helps to reduce heat loss. The contents are kept molten for some hours to ensure uniformity, as well as to permit the vaporization of some impurities. The cup is then lowered very slowly out of the heating coil, typically over a 12-hour period. Useful crystal growth begins at the bottom of the melt. As can be seen in section B of figure 4, crystals nucleate and form parallel columns near the bottom and grow upwards. They continue to grow until the whole melt has solidified, as in section C, whereupon the power is shut off.

The growth process under way is shown in figure 1, and half of a "skull"—the solidified crystals with the surrounding crust—is shown in figure 5. A "dopant," a purposely added impurity, had been used to produce yellow cubic zirconia in this growth run. Light tapping will separate the crystal columns, which appear as in figure 6. Annealing, typically at 1400°C (2552°F), in air or in oxygen may be used at times to remove residual strain to remove any discoloration resulting from a slight oxygen loss, or to adjust the valence states of impurities.

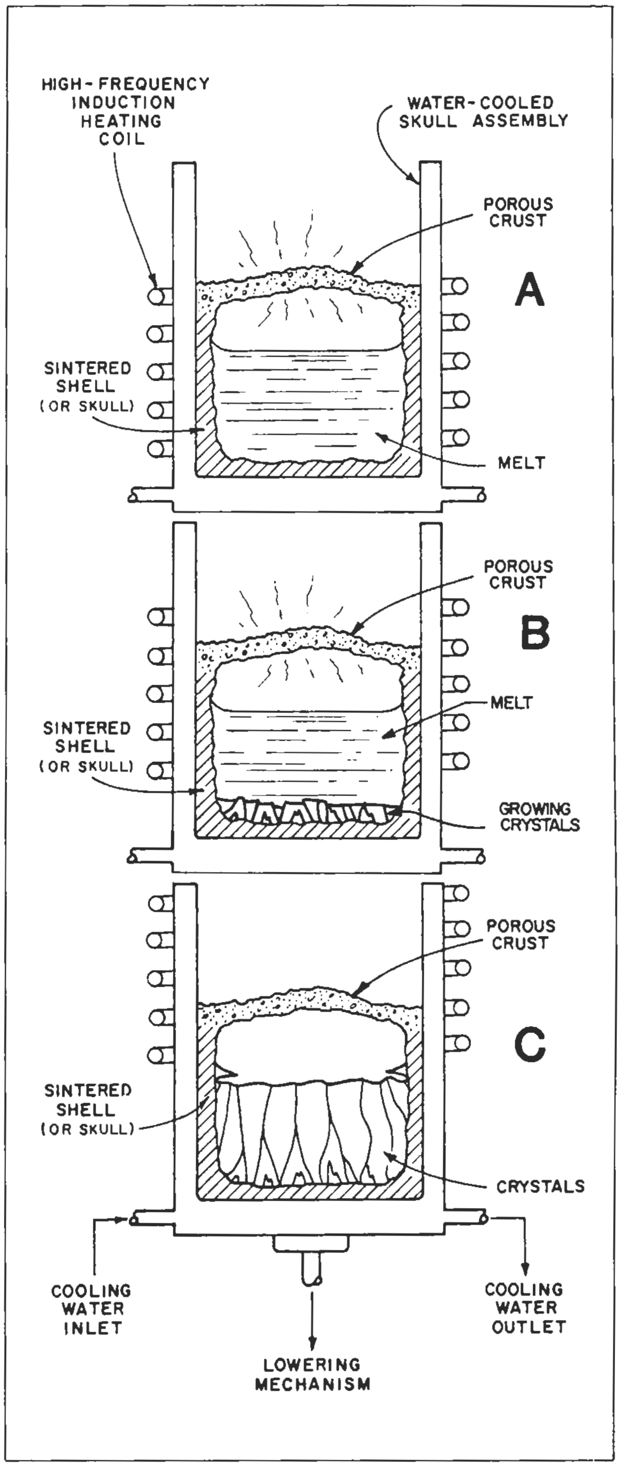

Figure 4. The process of solidification during skull-melting crystal growth. A = formation of a porous crust over the top of the melt, B = early growth of parallel columns of crystal nucleate, and C = final stage, with the entire melt solidified by the crystal growth.

Figure 5. Half of a large skull of yellow cubic zirconia crystals grown using the technique described in figure 4. Courtesy of the Ceres Corp., Waltham, MA.

At first, a skull 3 inches (7.5 cm) in diameter was considered the state of the art for cubic zirconia crystals, but today skulls 12 inches (30 cm) in diameter and weighing 150 lbs. (68 kg), such as the one shown in part in figure 5, are produced. These yield about 100 lbs. (45.5 kg or 227,000 carats) of usable rough. Individual crystals are well over one inch (2.5 cm) wide and several inches long; stones several hundred carats in weight have been faceted. The economy of large-scale production is significant, although the rather high cost of the high-purity starting material is not much affected by such a scale-up.

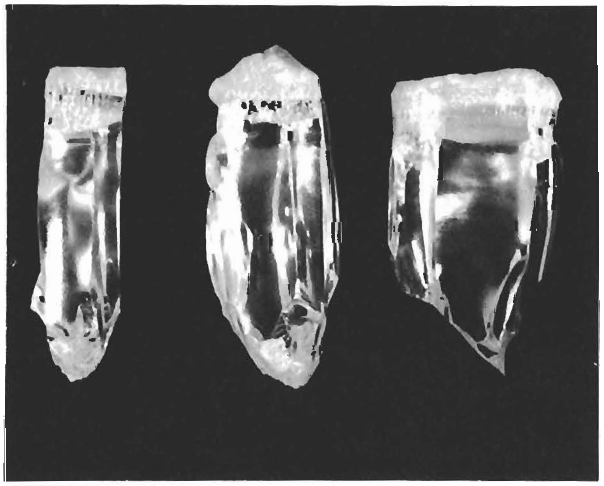

Figure 6. Columnar crystals of cubic zirconia one inch (2.5 cm) across.

THE CURRENT STATUS OF COLORLESS CUBIC ZIRCONIA

Starting from a small amount in 1976, within just four years production has grown to an estimated 13 tons (12,000 kg or 60 million carats) of cubic zirconia per year at the end of 1980. Corresponding to the figures for rough material, the annual production of faceted material is estimated at about 3 tons (2700 kg or 13.5 million carats) per year. During this same time period, the wholesale price per faceted carat has fallen from an initial US $40 or more to US $4 or less, varying of course with the quality of the material and the faceting, as well as with size, shape, and quantity.

It is interesting to compare the production data for cubic zirconia with the data for synthetics previously used as diamond imitations, as shown in table 1. Annual production of cubic zirconia has already well surpassed the YAG peak of 1972 which, it must be remembered, represented overproduction, was more than the market could absorb, and resulted in the discontinuation of production by a number of manufacturers. A reasonable guess would be that the equivalent stage for cubic zirconia is close at hand. A factor that may prevent this from happening is the apparent opening up in recent months of the European market, where previous diamond imitations never achieved significant popularity.

Many jewelry retailers at first showed a strong resistance to handling cubic zirconia, but experience has now demonstrated that the simulant has had no significant effect on diamond sales, occupying instead a separate niche in the jeweler's range of goods. The available data for 1977 permitted an estimate of the retail value of all diamond imitations sold in the United States of about $20 million, compared to about $2000 million for diamonds (Nassau, 1980a). Although by now the sales figure for diamond imitations has grown significantly, so has the figure for diamonds, and the 1% ratio of diamond-imitation sales to diamond sales has probably increased only a little.

Major manufacturers of cubic zirconia in the U.S. include the Ceres Corporation of Waltham, MA (marketing through MSB Industries of New York City); ICT Corporation of Shelby, MI; Singh Industries of Randolph, NJ; the Lambda/Airtron Division of Litton Systems of Morris Plains, NJ; and Commercial Crystal Laboratories of South Amboy, NJ. Outside the U.S. there is production

TABLE 1. The historical sequence of synthetics used as diamond imitations.

Synthetic	Year of initial use	Peak annual production of rough (in carats)	Year of peak
Sapphire	After 1905	?	?
Spinel	About 1920	?	?
Rutile	1948	750,000	1955
Strontium titanate	1955	1,500,000	1968
YAG	1968	40,000,000[a]	1972[a]
GGG	1975	Small	1976
Cubic zirconia	1976	60,000,000[b]	1980–1981[b]

[a] *Premature peak due to overproduction.*
[b] *May still be increasing.*

in Moscow, USSR (marketed in the U.S. through Clayhill Resources of New York City); at V. Djévahirdjian S.A. of Monthey, Switzerland (at first erroneously reported as using flux-growth [Nassau, 1976]); as well as recent production in Taiwan and undoubtedly elsewhere. The rough material is faceted all over the world, but until recently almost all has been used in the U.S. Despite the great improvement of cubic zirconia over YAG (in brilliance) and over strontium titanate (in hardness), both of these other simulants continue to be manufactured and sold, albeit on a considerably smaller scale.

Claims are sometimes made that one manufacturer's cubic zirconia is better than another's, for example, in respect to turning dark in normal use. Although some bad batches were undoubtedly produced in the early days, currently there is no significant difference in the behavior of the high-grade material produced by the various manufacturers. Similarly, inclusions are virtually absent in top-grade material.

Names used for marketing cubic zirconia include:

- CZ
- Cerene
- Cubic Z
- Cubic Zirconia
- Cubic Zirconia II
- Cubic Zirconium
- Cubic Zirconium Oxide or Dioxide
- Diamon-Z
- Diamond-QU
- Diamonair II
- Diamonesque
- Diconia
- Diamonique III
- Diamonite or Diamondite
- Djevalite
- Fianite
- Phianite or Phyanite
- Shelby
- Singh Kohinoor
- Zirconia
- Zirconium
- Zirconium Yttrium Oxide

Some of these names are registered trademarks, others are not. It is important to note that, by themselves, *zirconium* and *cubic zirconium* are misnomers, since they would refer to zirconium metal! Also, some sellers are using the ending "—Z" with other terms, possibly to imply cubic zirconia when this may not, in fact, be the material at hand.

The stabilizer used in cubic zirconia is usually Y_2O_3, although CaO has also been used. The phase diagrams indicate that up to 65 weight percent Y_2O_3 or up to 14 weight percent CaO could be used in cubic zirconia. Too much stabilizer results in a softer and less brilliant product, however, and amounts much smaller than those indicated in the phase diagrams are used for the commercial product, as described in the Appendix.

Now that large crystals of cubic zirconia are readily available at a relatively low cost, scientists are once again studying the material for possible technological uses, thus coming full circle to the original purpose for growing the crystals!

Cubic hafnia—hafnium oxide (HfO_2) stabilized with Y_2O_3—has also been described in the cubic zirconia patents. This has about the same refractive index as cubic zirconia, but with an even higher specific gravity. Since hafnia is much more expensive than zirconia, cubic hafnia is not likely to be used as a diamond imitation.

THE CUBIC ZIRCONIA PATENTS

In December 1972, the USSR group of V. I. Aleksandrov and coworkers applied for patents in the U.S. and other countries, the relevant claim being cubic zirconia stabilized with 10% to 30% yttrium oxide. British patent 1,373,888 was published on November 13, 1974, and German patent

2,261,851 appeared on July 11, 1974. The U.S. patent application was abandoned and then refiled in March 1977, was again abandoned and then refiled in January 1978; it issued on May 8, 1979, as U.S. patent 4,153,469.

Meanwhile, additional patents had been applied for in January 1975, leading to British patent 1,491,362, published on November 9, 1975, and German patent 2,501,800, published on July 22, 1976. The relevant claim in these patents was cubic zirconia stabilized with 5% to 10% yttrium oxide. Such a claim may also have been involved in one of the U.S. refilings; if so, it was apparently not allowed. It should be noted that the items being patented are the chemical composition of cubic zirconia crystals, not the growth technique.

After the issuance of the U.S. patent in 1979, some retailers hesitated to purchase domestically produced material. At least one U.S. producer (the Ceres Corp.) guaranteed its customers that it would defend them in any suits that might arise from this patent. A suit based on this patent has, in fact, been filed; as of this writing it is still undecided. It should be noted that most cubic zirconia produced in the U.S. is believed to be made with somewhat less than the 10% minimum claimed in the patent. Even if this argument were rejected, there is the fact that the patent contains no mention of the cubic zirconia stabilized with 12.5% Y_2O_3 reported in 1969 (Roulin et al.) and shown in large crystal form in a French film made at that time; this would seem to imply that a court test of the validity of the patent might well result in an invalidation.

COLORED CUBIC ZIRCONIA

Aleksandrov and coworkers gave details on the manufacture of colored cubic zirconia in their 1972 patent application. Until recently, however, most manufacturers have concentrated on keeping color out of their crystals, since even trace amounts of impurities such as iron can produce a yellow hue, undesirable in a diamond imitation. Some experimentation persisted, though, particularly to find good ruby red and emerald green colors, neither of which seems to have been achieved thus far. Along the way, significant amounts of yellow and other colored material accumulated. Some was faceted by amateurs for the fun of it and was found to be very attractive.

A major breakthrough in the market for colored cubic zirconia was apparent at the 1979 Tucson (Arizona) Gem and Mineral Show, where all available colored cubic zirconia rough was quickly bought up by amateur as well as professional cutters. The attractiveness of the colors lies in their coupling with a high refractive index and dispersion, and can be seen to some extent in figure 7. The optical constants of most colored gemstones—ruby, sapphire, emerald, amethyst, citrine, topaz, etc.—have relatively low values, and their attractiveness resides predominantly in the color. With colored cubic zirconia, however, there is considerable brilliance, or "life," in addition to the color; this liveliness can be transmitted only poorly in even the best photograph.

A listing of the colors produced by specific dopants (purposely added impurities) is given in table 2, and the dopant compounds used to produce desired colors appear in table 3. The nature of the color can change with the concentration of the dopant as well as with its oxidation state, and combinations of dopants are used to obtain desired shades. Just some of the colors produced by one manufacturer are shown in figures 7 and 8. The manner in which allochromatic transition metal impurities produce colors is described elsewhere (Nassau, 1974–75, 1980a, and 1980b).

The most frequently used colors at present are (1) the amethyst to lavender to lilac range, (2) the yellow (canary) to orange to reddish-brown range, and (3) pink. Colored cubic zirconia produces faceted stones that are much more "lively" than the analogous amethyst or purple sapphire for the first color group and citrine, padparadsha sapphire, imperial topaz, or garnet for the second. Prices for colored rough are somewhat higher than for the colorless. At present, these colored stones seem to be used primarily for fad-type medium-priced fashion jewelry. The quantity of colored cubic zirconia produced is still quite small but is increasing rapidly and may soon represent a significant portion of the market. Attractive intense greens, blues, and reds have not been produced thus far.

Were it not for the relative rarity of colored diamonds and the fact that most people are not familiar with them, these colored cubic zirconias would provide excellent imitations for naturally occurring canary, pink, blue, and green diamond. Jewelers should indeed be aware that, with the correct shade and intensity of color, these cubic zirconias could easily be mistaken for colored diamonds.

Figure 7. Faceted cubic zirconias; the largest is 9 mm across. Courtesy of the Ceres Corp., Waltham, MA, and MSB Industries, New York, NY.

TABLE 2. Colors produced by specific dopants added to cubic zirconia.[a]

Dopant	Symbol	Color
Cerium	Ce	Yellow-orange-red
Chromium	Cr	Olive
Cobalt	Co	Lilac
Copper	Cu	Yellow
Erbium	Er	Pink
Europium	Eu	Pink
Holmium	Ho	Pink
Iron	Fe	Yellow
Manganese	Mn	Brown-violet
Neodymium	Nd	Lilac
Nickel	Ni	Yellow-brown
Praseodymium	Pr	Amber
Thulium	Tm	Green
Titanium	Ti	Yellow-brown
Vanadium	V	Green

[a] *Typically at the few tenths of a percent level; the color achieved may depend on the oxidation state of the dopant.*

TABLE 3. Dopants used in cubic zirconia to give desired colors.

Color range	Dopants used
Yellow-orange-red	CeO_2, Ce_2O_3
Yellow-amber-brown	CuO, Fe_2O_3, NiO, Pr_2O_3, TiO_2
Pink	Er_2O_3, Eu_2O_3, Ho_2O_3
Green-olive	Cr_2O_3, Tm_2O_3, V_2O_3
Lilac-violet	Co_2O_3, MnO_2, Nd_2O_3

PROSPECTS FOR THE FUTURE

In chapter 1 and the epilogue of my book (Nassau, 1980a), there is an extensive discussion of the sources of new synthetics as well as of the way in which these sources have been changing over the years. Today, only the most difficult of the syntheses have not yet been achieved and, as crystal growth techniques have become ever more sophisticated, the search for new crystals has become more costly and time consuming.

Figure 8. Colored cubic zirconia rough; the largest piece is 2.5 inches (6.5 cm) long. Courtesy of the Ceres Corp., Waltham, MA.

It is, therefore, hardly a coincidence that the most recent diamond imitations—YAG, GGG (gadolinium gallium garnet), and cubic zirconia—all originated as spin-offs from technological research. The use of YAG as a laser material is well known, GGG was developed as a substrate for magnetic bubble memories, and cubic zirconia was studied as a possible laser or opto-electronic material. Is it then likely that this source will produce another material that might provide a diamond imitation that is superior to cubic zirconia?

I believe the answer to this question is *yes,* but a qualified *yes.* Although such a material will undoubtedly appear sooner or later, it must be realized that technological research for new materials has slowed significantly. In part, this is because present needs have been largely filled and the areas left to be explored are becoming smaller; in part, it is because existing materials are being studied intensively so as to utilize their potentials more fully. So it may not be all that soon that a potential successor to cubic zirconia will arrive.

Further qualifications arise from two factors. First, the optical constants of cubic zirconia are sufficiently close to diamond in a material of adequate hardness and wearability that a large improvement cannot be expected. This was hardly true of any of the previous diamond imitations. Second, the cost involved in developing and marketing a new synthetic or imitation is never small and, given the existence of a highly satisfactory material in the marketplace, may not be justifiable in terms of the potential returns. (One may note the difficulty synthetic flux-grown rubies have had in achieving market penetration in competition with the Verneuil-grown product; they recently came close to success by posing as natural rubies with forged GIA certificates!) All in all, it would seem that cubic zirconia is likely to be with us for quite some time.

APPENDIX: TECHNICAL AND GEMOLOGICAL DATA AND IDENTIFICATION

Composition. Typically zirconia (zirconium [di]oxide, ZrO_2) containing about 10 mol. percent yttria (yttrium oxide, Y_2O_3) or 15 mol. percent lime (calcium oxide, CaO). Zirconia can exist in several polymorphic structures, as listed in table 4.

Structure. Same as that of fluorite, CaF_2, with Zr in place of Ca and O in place of F. This structure, shown in figure 9, consists of a simple cubic arrangement of oxygens with every other cube occupied by a Zr. Each O is surrounded by four Zr, each Zr by eight O. When ZrO_2 is stabilized with either Y_2O_3 or CaO, there are fewer than two oxygens per metal atom, and some oxygens are missing: one O for every two Y or one O for every Ca, as is implied in the typical formulations $Zr_{0.90}Y_{0.10}O_{1.95}$ and $Zr_{0.85}Ca_{0.15}O_{1.85}$. Some Zr and some dopants may have only seven or six O around them instead of the usual eight; this changes the crystal field and, accordingly, the color (Nassau, 1974–75, 1980a, 1980b).

Crystal Symmetry. Cubic; class, $4/m\bar{3}2/m$; space group, *Fm3m*.

Optical Properties. Refractive index, 2.15 to 2.18; no birefringence, singly refracting; dispersion, 0.058 to 0.066.

Mechanical Properties. Hardness, 8.0 to 8.5 (a slight anisotropy in hardness appears to be present; this is possible even in the cubic system and also occurs in diamond); specific gravity, 5.6 to 6.0; no cleavage; conchoidal to uneven fracture; somewhat brittle; good wearability.

Inclusions. Small particles (Nassau, 1976, 1977, and 1980a; Liddicoat and Koivula, 1978), gas bubbles (Nassau, 1976), and a curious striated appearance (Nassau, 1976, 1977, and 1980a) can sometimes be seen but are absent in good-quality material.

Effect of Exposure to Ultraviolet and Other Irradiations. Variable fluorescence, may be completely absent; often turns brown, depending on quality, nature, and length of irradiation. Good-quality material will again fade to colorless when placed in sunlight for a few hours and will not darken in sunlight, that is, "solarize."

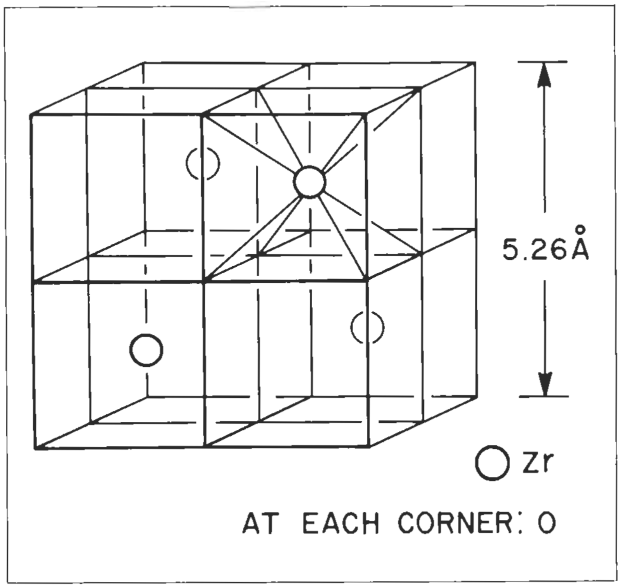

Figure 9. The crystal structure of cubic zirconia.

TABLE 4. The polymorphs of zirconium oxide.

Structure	Temperature range (°C)[a]	Unit cell parameters (Å)	Specific gravity
Monoclinic $P2_1/c$	Up to 1100	a = 5.15, b = 5.21 c = 5.31, β = 99°23′	5.83
Tetragonal $P4_2/nmc$	1100 to 2000	a = 3.64, c = 5.27	5.86
Hexagonal (?)	About 1900	a = 3.60, c = 5.90 (5.88)	6.13
Cubic[b] *Fm3m*	2300 to 2750	a = 5.26	5.64
Cubic[c] *Fm3m*	Up to melting	a = 5.12	6.00
Cubic[d] *Fm3m*	Up to melting	a = 5.12 to 5.16	5.60 to 6.00

[a] *The exact temperatures depend on the impurities present and the amounts thereof.*
[b] *The unstabilized high-temperature form of pure* ZrO_2.
[c] *The natural stabilized material of von Stackelberg and Chudoba (1937).*
[d] *The synthetic stabilized material.*

Distinction from Diamond. Several articles in this journal have dealt with various aspects of this problem (Liddicoat and Koivula, 1978; Nassau, 1978–79a, 1978–79b, 1981; Nassau and Schonhorn, 1977–78; Shaw, 1978). The distinction is obvious to the trained, aware eye. In a loose stone, the high specific gravity is readily apparent. Flatness of faces and sharpness of edges are not foolproof criteria, and girdles apparently showing "naturals" have been observed on cubic zirconia (Liddicoat and Koivula, 1978; Nassau, 1978–79b). The uniquely high thermal conductivity of diamond provides an unambiguous identification of diamond when a well-compensated instrument such as the Ceres Diamond Probe (Nassau, 1978–79a) is used, but some care is required with a simpler instrument such as the pocket-sized Ceres Czeckmate. A comprehensive test of such instruments, including the GEM Diamond Master is under way (Nassau, to be published). The breath test is a zero-cost version of the thermal conductivity test but requires comparison stones (Nassau, 1978–79b). Although there are some limitations, one of the many reflectivity meters should give a clear distinction (Liddicoat and Koivula, 1978; Nassau, 1978–79b). Finally, the wetting contact angle (Nassau and Schonhorn, 1978–79) provides a distinction when the GEM Diamond Pen or one of a number of other pens is used (see Shaw, 1978, for a discussion of the GEM Diamond Pen, and Nassau, 1978–79b, for a discussion of that and other pens), but surface coatings may have to be removed. As always, the gemologist must guard against the possibility of a doublet.

Size, Weight, and Shape. Proportions and cutting techniques have been discussed (Kerr, 1979). A graph for the rapid conversion of size to weight and to the equivalent diamond weight has also been given (Nassau, 1979 and 1980a). It should be noted that cubic zirconia stones may be sold by size, by weight, or by equivalent diamond weight (the last is not always so specified).

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A SIMPLE APPROACH TO DETECTING DIAMOND SIMULANTS

By Jill Hobbs

This article offers a step-by-step approach to the identification of the most problematic diamond simulants. The optical and physical properties of diamond are contrasted to those of colorless strontium titanate, synthetic cubic zirconia, gadolinium gallium garnet, and yttrium aluminum garnet. If the testing methods discussed in this article are used, none of the above materials should be mistaken for diamond.

Diamond simulants need not frighten the gem identifier. Quick methods of identification are available, with many clues requiring only a trained eye. Although certain clues when used alone cannot establish the identity of the stone, often two or three of these clues considered together will lead to the identification of the gem material. Even if the clues available are insufficient for positive identification of the material at hand, other tests have been developed that at least prove whether or not the stone in question is a diamond.

The intent of this article is to provide a step-by-step approach to the identification of colorless diamond simulants. The methods and techniques described are not new, but they have been arranged in such a way here to present a relatively simple, systematic approach to diamond identification. Basically, the approach involves the following:

1. Train your eyes to recognize as many visual characteristics of simulants as possible. A "trained eye" may spot a possible simulant without the use of laboratory equipment.
2. Know and use basic tests to identify the type of diamond simulant. Even though your primary concern is probably not to name the simulant, it is helpful to be able to provide your customer with such information.
3. Stay abreast of the development of new instruments that identify loose or mounted diamonds. While in most cases such devices do not identify the type of simulant, they are very helpful at the repair or take-in counter, where employees may not have the training to recognize diamond simulants by their visual characteristics or with the basic tests.

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Acknowledgments: The photographs were taken by Michael R. Havstad and the line illustrations in property charts A and B were drawn by Peter Johnston, Gem Media, Gemological Institute of America, Santa Monica, CA.

Author's note: Strictly speaking, the word *stone* should be used to refer only to natural materials. For simplicity, the term is used here to refer to simulants as well as to diamond.

Of all the techniques available for diamond separations, perhaps the most important is the trained eye. If a machine fails, or if you cannot perform other verifying tests, your eyes may alert you to a possible simulant. The training requires a great deal of practice and continual updating, but visual examination can be performed anywhere, anytime.

This article focuses on the identification of the four diamond simulants that cause the most confusion for the jeweler: (1) strontium titanate, (2) synthetic cubic zirconia (CZ), (3) gadolinium gallium garnet (GGG), and (4) yttrium aluminum garnet (YAG). All of these stones share two properties with diamond: each is over the limits of the conventional refractometer, and each is singly refractive in optic character. The properties of diamond and these four diamond simulants are listed in property chart A. The stones are listed in order from highest to lowest refractive index. The properties of these materials are arranged from left to right in the order in which they are presented in this discussion.

Other significant materials that have been mistaken for diamond are listed in property chart B. They are: synthetic rutile, zircon, synthetic sapphire/synthetic corundum, synthetic spinel, glass, and assembled stones. For convenience, these stones and their properties are arranged the same as chart A. All these materials are more easily identified than those in chart A because they either have refractive indices within the range of the conventional refractometer or they are doubly refractive. Chart B is, then, supplemental information. The following article assumes that the reader is familiar with the properties of the materials listed on chart B, and does not have difficulty identifying them. For more information on these stones, refer to the newly revised GIA Diamond Assignment number 36.

VISUAL CHARACTERISTICS THAT SEPARATE DIAMOND FROM DIAMOND SIMULANTS

As yet, no diamond simulant has been developed that fully duplicates the appearance of a diamond. A diamond has unique optical and physical properties that make its appearance distinctive.

The four diamond simulants that cause the most confusion for the jeweler—CZ, GGG, strontium titanate, and YAG—have many visual traits that are unlike those of diamond. The different visual characteristics reflect differences in the optical and physical properties of the various materials.

The "Read-Through" Effect. The visual trait that is often noticed first in round-brilliant-cut stones is the read-through effect. When the various diamond simulants are tilted or placed table-down on paper, each one "reads through" differently; that is, each simulant allows a different amount of light to be transmitted through the stone at different angles. This trait is related to the stone's refractive index, critical angle, and proportioning.

Fancy shapes (e.g., marquise, oval, pear) usually read through to some extent regardless of the material involved (the proportioning of fancy cuts allows for greater light transmission). Properly cut in a round-brilliant shape, however, diamond and strontium titanate will generally not read through, while CZ, YAG, and GGG will. When the stones are placed in order of ascending refractive indices, the succession is as follows: YAG, GGG, CZ, strontium titanate, and diamond. YAG has the lowest refractive index and diamond the highest. (An easy way to remember the order is by associating the first letter of each of the stones with this phrase: *Y*ou *G*o *C*razy *S*taring at *D*iamonds). If a diamond and the above four diamond simulants are cut to approximately the same size and proportion, the stones with the lowest refractive indices can be read through most easily.

If the stones are placed table-up in a tray, the read-through effect is apparent when the stones are tilted. In figure 1, this effect is seen where an orange paper has been placed in back of the stones to make the effect more visible. Note that the orange paper can easily be seen through YAG, but not through diamond. At different angles, the "read-through" character of each stone varies. However, only when the tray is tilted to the angle where the stones almost spill will diamond transmit the orange of the paper. And, at that point, the amount of orange that can be seen through the diamond is still less than for any of the other materials. Again, the amount of orange seen in each of the five stones gradually increases in relation to the refractive index of each.

The read-through effect can be particularly helpful when examining a parcel of round-brilliant-cut diamonds. Simply line the stones table-up, and then tilt the paper away from you. The lining or cotton inside the parcel paper should il-

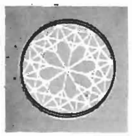
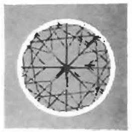
PROPERTY CHART A
DIAMOND AND COLORLESS SIMULANTS

Gemstone	Refractive Index	Read Through[a]	Dispersion	Color on Pavilion	Hardness	External/ Internal Characteristics	Specific Gravity	Reflection Pattern	Typical Fluorescence[b]
Diamond	2.417	None, if properly cut	0.044	Orange or blue on a few facets	10	Bearding, natural with trigons, grainings, cleavage, included crystal	3.52		Weak to strong blue (lw and sw); may fluoresce any color
Strontium titanate	2.409	None, if properly cut	0.190	Spectral colors, widespread	5–6	Gas bubbles	5.13		Generally inert
Synthetic cubic zirconia	2.15	Slight	0.060	Orange over most of pavilion	8½	Negative crystals, lined or partially lined with zirconium oxide powder	5.95		None to weak-moderate orange (lw); none to weak-moderate yellow, or greenish yellow (sw)
Gadolinium gallium garnet	1.970	Moderate	0.045	None, or orange over most of pavilion	6½	Gas bubbles, metallic platelets	7.05		None to moderate orange (lw); moderate to strong orange to pinkish orange (sw)
Yttrium aluminum garnet	1.833	Strong	0.028	None, or blue over most of pavilion	8½	Gas bubbles	4.55		None to moderate orange (lw), none to weak orange (sw)

[a] *This technique is meaningful only with round-brilliant-cut stones.*

[b] *lw = long-wave ultraviolet light; sw = short-wave ultraviolet light.*

PROPERTY CHART B
COLORLESS DIAMOND SIMULANTS

Gemstone	Refractive Index	Read Through[a]	Dispersion	Color on Pavilion	Hardness	External/ Internal Characteristics	Specific Gravity	Reflection Pattern	Typical Fluorescence[b]
Synthetic rutile (yellow body color)	2.616–2.903[c]	None	0.330	Various spectral colors widespread	6–6½	Gas bubbles	4.26		Generally inert
Zircon (high property)	1.925–1.984[c]	Moderate	0.038	Blue over most of pavilion; may exhibit orange	7½	Liquid in two-phase or fingerprint pattern	4.70		None to weak yellow (lw & sw)
Synthetic sapphire Synthetic corundum	1.762–1.770[c]	Very strong	0.018	Blue over most of pavilion	9	Gas bubbles, possibly in thread-like pattern	4.00		None to weak bluish white (sw)
Synthetic spinel	1.730	Very strong	0.020	Blue over most of pavilion	8	Gas bubbles	3.64		Moderate to strong bluish white (sw)
Glass	1.48–1.70	Extreme	0.009–0.098 (usually about 0.037)	Variable	5–6½	Gas bubbles, concave facets, mold marks, flow lines, orange-peel effect	2.30–4.50		Variable colors (lw & sw); often white overtones
Assembled stones	Same to different readings on crown and pavilion	Variable	Variable; possibly different on crown and pavilion		Variable	Separation plane; gas bubbles near cement, crazing in cement; variable inclusions	Variable	Variable	Variable

[a] *This technique is meaningful only with round-brilliant-cut stones.*

[b] *lw = long-wave ultraviolet light; sw = short-wave ultraviolet light.*

[c] *Doubly refractive.*

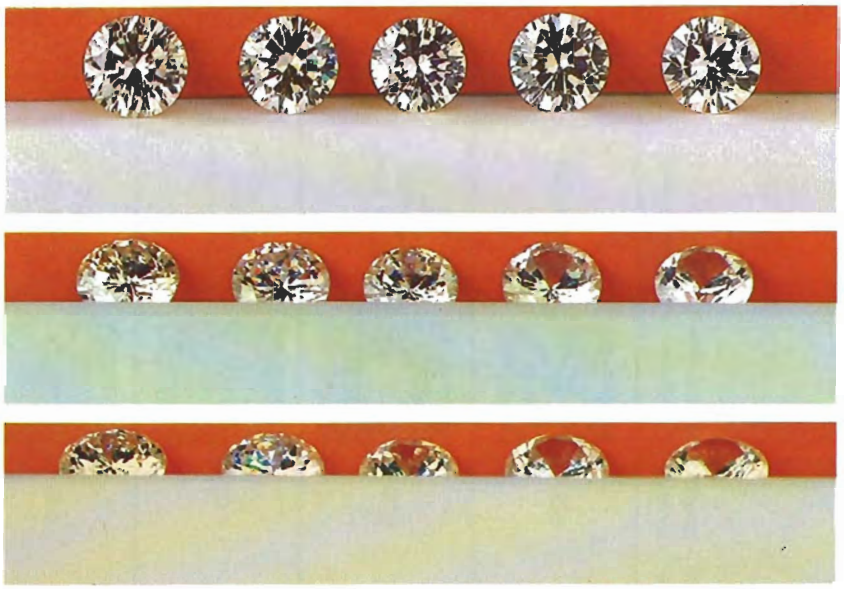


Figure 1. Diamond and its simulants will have different degrees of transparency, or read-through effect, if all are well-proportioned round brilliants. The lower the refractive index of the stone, the more obvious the read through is. Also, the greater the tilt, the clearer the read through is. Order from left to right (high to low R.I.): diamond, strontium titanate, CZ, GGG, YAG.

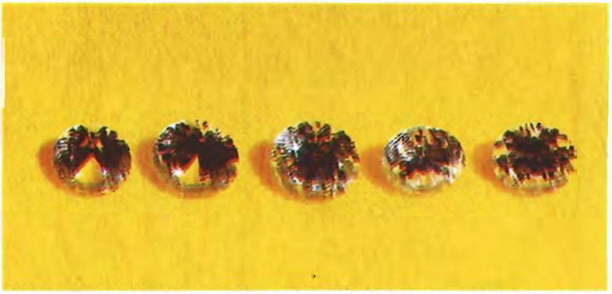


Figure 2. The read-through effect is seen on well-proportioned round brilliants when they are tilted on a light background, such as a stone cloth. Order from right to left: diamond, strontium titanate, CZ, GGG, YAG.

luminate the effect. Also, the stones do not have to be specially aligned before the results are visible. When a loose stone is placed in a stone cloth, the same results are evident. As you tilt or rock the stone inside the cloth, the degree of read through becomes evident (fig. 2).

The read-through effect can also be seen when the stones are placed table-down over a business card (fig. 3). With YAG, the letters of the business card are easily seen through the stone; the letters appear a bit magnified and slightly rounded, but they are still very readable. As the refractive index of the material increases, read through becomes progressively more difficult. Through GGG, the letters appear twisted; through CZ, they are almost indistinguishable. However, even a small amount of read through may aid in identification because diamond and strontium titanate do not read through in this position. (Synthetic rutile will also not read through, but it is easily identified on the basis of its other visual characteristics, as per property chart B).

In short, the read-through effect is a quick "indication" test, that is, a test that does not prove, but leads to, the identity of the material. It can be performed with simple aids such as a stone cloth, a business card, or parcel paper. The results are consistent provided that all the stones are well-proportioned round brilliants. YAG, GGG, and CZ will wash out or read through, while diamond and strontium titanate will not.

Figure 3. The read-through effect is also noted when round-brilliant-cut stones are placed table-down over a printed page. Order from left to right: diamond, strontium titanate, CZ, GGG, YAG.

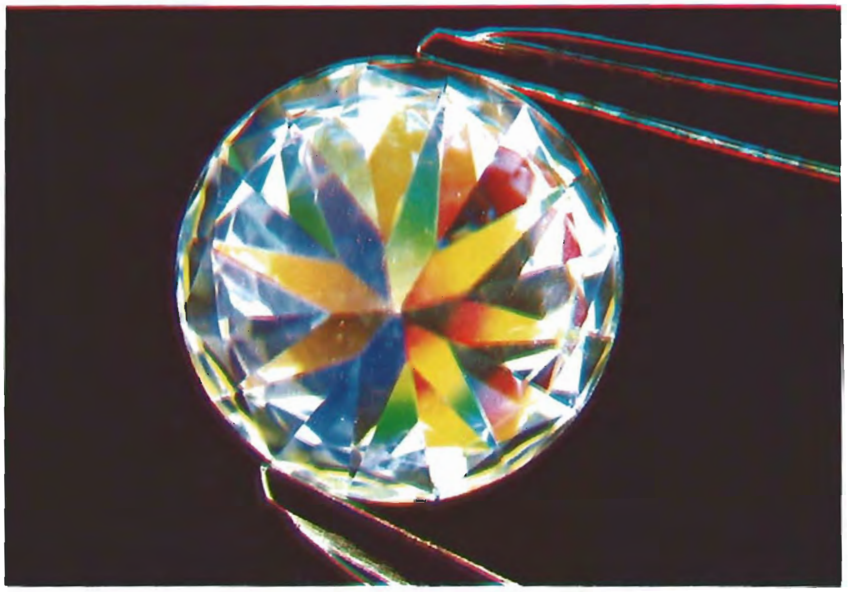


Figure 4. Spectral colors seen as a result of dispersion. Magnified 10×.

To obtain meaningful results, the tester should have comparison stones, or have sufficient experience with diamond simulants to recognize the different degrees of read through of the various stones.

Dispersion and the Monochromatic Flash. If the stone is a properly cut round brilliant and has no read-through effect, it is most likely diamond or strontium titanate. At this point, the difference in the dispersion values of the two stones will easily separate them.

Dispersion is the ability of a substance to cause light to divide into its spectral colors. For example, when light is transmitted through a prism, a series of colors—red, orange, yellow, green, blue, indigo, and violet are seen, as illustrated in figure 4. Angular pieces of glass that hang in a chandelier often display dispersion. A cut stone has the same ability to break up light into these colors, although the distinctness of the colors that emanate varies with the material.

Studies have determined the amount of dispersion in each of the diamond simulants (see property chart A). How do the numerical values relate to the visual effect? The visual approximation of dispersion takes more time to master than does read through; however, once mastered, it can help to build a case for the identity of the material. The best way to judge dispersion is to reflect light off the surface of the stone and look closely at the crown and bezel facets.

With regard to the two materials that do not show read through, the dispersion of strontium titanate (0.190) is over four times that of diamond (0.044)—a difference not easily overlooked. Strontium titanate is literally "on fire," while diamond displays a moderate amount of spectral colors.

Of the three diamond simulants that do display read through—YAG, GGG, and CZ—none has the dispersion of strontium titanate. YAG has the lowest dispersion value (0.028) and the spectral colors are hardly visible. In appearance it almost resembles a low-lead-content glass; the lack of dispersion and extreme read through make YAG a lifeless simulant. GGG does not appear to have much dispersion. Its value (long thought to be 0.038, but recently verified as 0.045; Nassau, 1980, p. 148) is very close to that of diamond, yet the spectral colors do not seem as prominent. CZ, however, has a good deal more dispersion than diamond. The spectral colors are always evident, but the amount of dispersion is such that the stone is not always distinguishable from diamond (0.060 vs. 0.044) on this basis alone. In the event that there continues to be some uncertainty, the stone could be examined for a monochromatic color on its pavilion, as explained below.

On many of the gem simulants, one spectral color predominates on the back (pavilion) of the cut stone, creating an umbrella effect. The color is the result of dispersion, and the breadth of its circumference is the key to its usefulness as a visual aid. The monochromatic sheen can be seen

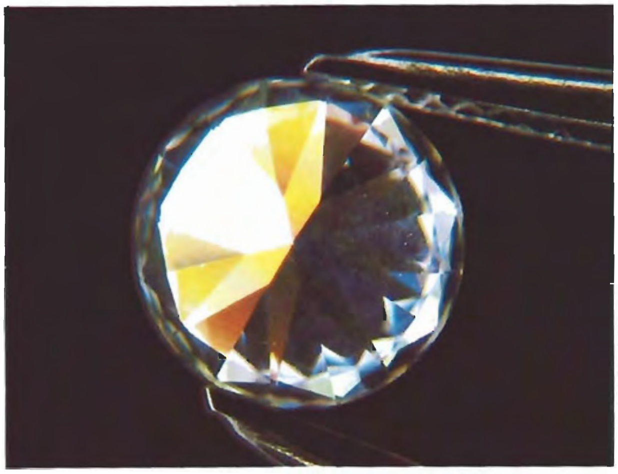


Figure 5. Dispersion: orange commonly covers a large area on the pavilion of CZ. Magnified 10×.

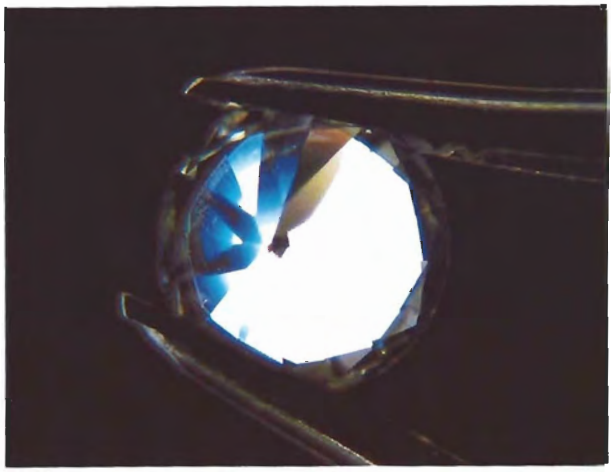


Figure 6. Dispersion: blue often covers a large area on the pavilion of YAG. Magnified 10×.

in reflected or transmitted light. The unaided eye might notice the color as light is reflected off the pavilion of the gemstone. Under a microscope, it is easily seen with dark-field illumination, that is, light directed at the gem from the side. Position the stone table-down, and gently tilt it in different directions.

Colorless cubic zirconia generally exhibits an orange flash over most of its pavilion surface (fig. 5). At times, the color seems restricted to one-half of the pavilion until the stone is gently rocked, in which case the orange usually extends over the other half as well. This orange effect is prevalent on most cuts of cubic zirconia. GGG may also exhibit an orange-flash effect, but generally the orange is not as extensive.

YAG often shows a blue color on one-half of its pavilion surface (fig. 6). The results are not as consistent as with cubic zirconia, but they may still aid in identification. (The only other diamond simulants to exhibit the blue effect are within the limits of the refractometer, i.e., synthetic sapphire and synthetic spinel.)

Diamond usually does not display a monochromatic color over most of its pavilion surface. It may show blue or orange, but in most cases these colors extend only across one or two facets (fig. 7). Thus, the significance of the monochromatic effect lies not only with the color present, but with the breadth of the color on the pavilion surface as well.

Figure 7. Dispersion: orange and blue extend over only a few facets of diamond. Magnified 10×.

In the identification process thus far, the diamond simulants have been examined for read through and the effects of dispersion. These visual traits can be seen in a glance. Just a quick look and turn of the stone can yield a great deal of information to a trained observer. However, since these characteristics do not prove the identity of the material, a loupe is useful as we proceed to the next steps of identification.

Facet Junctions. When a stone is examined using a loupe, one of the first external characteristics worth noting is the sharpness of the facet junc-

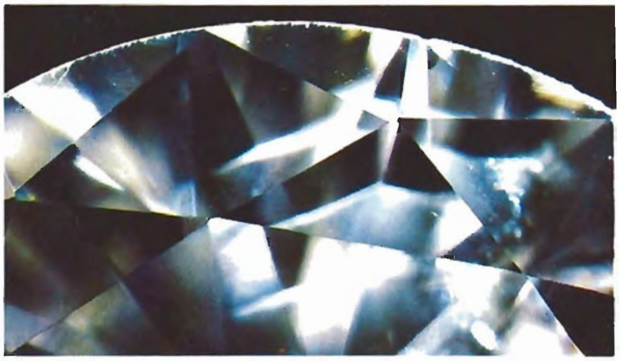


Figure 8. The facet junctions of diamond usually appear sharp and well defined because of the stone's exteme hardness. Magnified 30×.

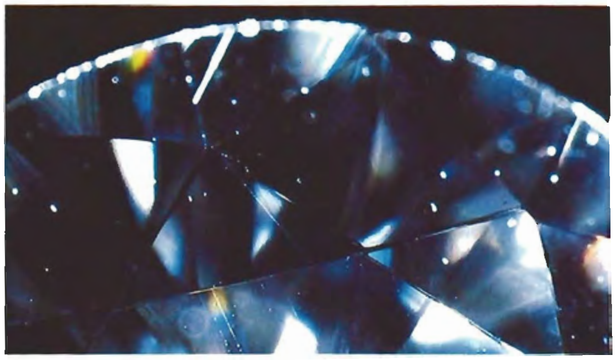


Figure 9. GGG often has rounded facet junctions because it has a hardness of only 6½. Magnified 40×.

tions. Because of diamond's extreme hardness (10 on the Moh's scale), its facet junctions are usually sharp and precise (fig. 8), whereas stones under 7 on the Moh's scale (e.g., GGG at 6½ and strontium titanate at 5–6) have a tendency toward rounded facet junctions (see figure 9). Diamond's facet junctions may become abraded over time, but they will not appear rounded.

Because of its relative softness, strontium titanate usually has heavily abraded facet junctions as well. CZ and YAG, on the other hand, have hardness values over 8, so their facet junctions appear relatively well defined. Again, though, CZ can be separated from diamond by the orange-flash effect, and YAG's lackluster appearance makes it distinctive. The roundness or sharpness of facet junctions is best seen in reflected light.

Girdle Area. Next, a trained eye might glean information from the girdle area, provided that it is not faceted. The girdle of a diamond appears mat and waxy after bruting. As illustrated in figure 10, it is not dull, like ground glass, but has the shiny appearance of wax (Bruton, 1973, p. 341). The girdles of most diamond simulants are polished. However, if they are not, the girdle appears quite dull, similar to that of unpolished glass. The girdles of simulants may look frosty, but never waxy. The girdle surface has neither the fine-grained look of a carefully turned diamond nor the poorer, coarser look of a diamond subjected to rapid bruting. In addition, sometimes the girdle of a diamond is "bearded," that is, marked by hairline feathers that extend into the stone (fig. 11). The

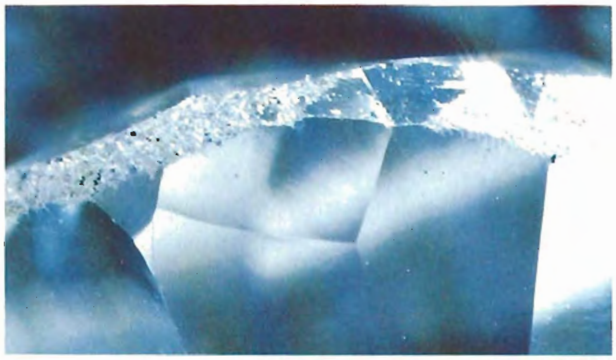


Figure 10. The girdle of a diamond often has a mat, waxy appearance. Magnified 40×.

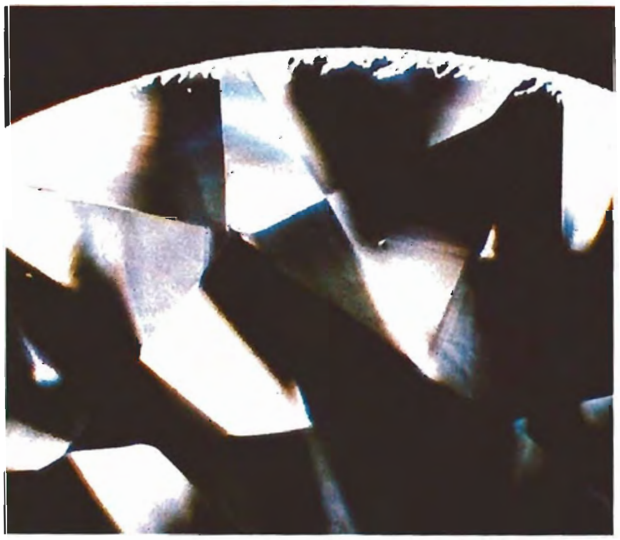


Figure 11. The girdle of a diamond may show bearding, or hairline feathers that extend into the stone. Magnified 30×.

Figure 12. A natural, or part of the original crystal surface, is often found on or near the girdle of a diamond. Magnified 35×.

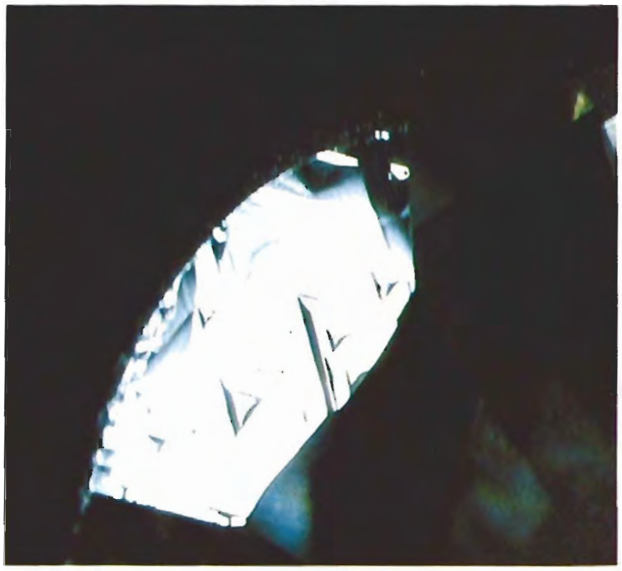


Figure 13. Trigons are growth markings that are often found on a natural and, to the experienced observer, prove diamond. Magnified 40×.

feathers are actually tiny fractures caused by rapid bruting. If seen, bearding signifies a diamond.

A natural is a part of the original crystal surface and is often seen on or near the girdle. Its unique luster distinguishes it from the rest of an unpolished girdle (fig. 12). To the experienced eye, a natural, too, signifies a diamond.

Growth markings may confirm the process under which the crystal grew and verify that the stone is, in fact, a diamond. Several growth markings are characteristic of diamond. Trigons, or triangular etch marks, may be seen on a natural, parallel to an octahedral face (fig. 13). Lines, or parallel grooves, are seen on those naturals that originate from a dodecahedral face; while square or rectangular depressions indicate a cube face.

Attempts have been made to duplicate these natural markings, but thus far the results have not been realistic. For example, attempts have been made to duplicate the appearance of trigons by marking triangles on the girdle of diamond simulants; instead of having the layered appearance of natural etch marks, however, the simulated markings appear to lie in one plane.

Inclusions. After the external characteristics of the material have been noted, the next step in identification is to examine the interior under magnification.

The chief reason for using a loupe is to find inclusions, which may prove whether or not the stone is man-made. With the emphasis on diamond certification today, most of us are acutely aware of the typical inclusions of diamond, such as cleavages, fractures, knots, and included crystals. While inclusions do not increase the value of a diamond, they can be extremely valuable in identifying one.

Most of the diamond simulants in the marketplace today are flawless, since manufacturers have perfected the techniques of crystal growth. If inclusions are seen, they are generally tiny white or highly reflective dots composed of various materials. In YAG, GGG, and strontium titanate, the tiny dots are usually gas bubbles, in which case high magnification may be needed to resolve them. In cubic zirconia, the whitish inclusions are small negative crystals that are lined, or partially lined, with a white powder that is probably unmelted zirconia oxide (Liddicoat and Koivula, 1978, p. 58). They may appear singly, or in rows. The only other significant inclusions found in diamond simulants are the triangular or hexagonal platelets seen in GGG.

Thus, if the material has inclusions typical only of natural stones, there is no doubt about the stone's identity. If tiny, round, high-relief inclusions are seen, the stone is probably man-made.

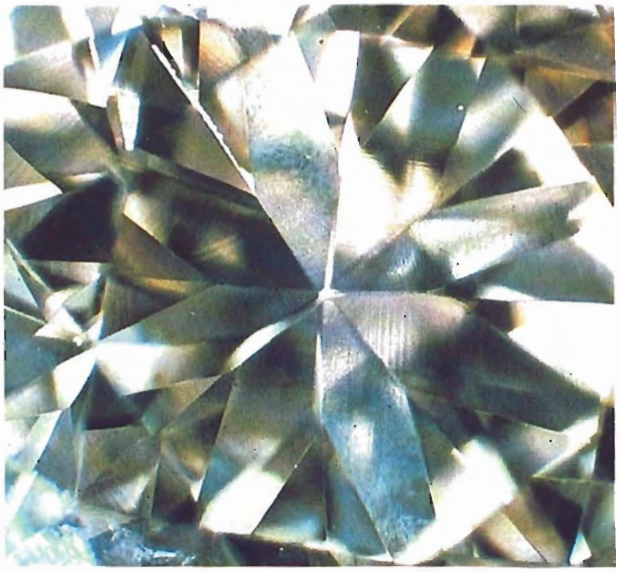


Figure 14. If visible, polishing marks on a diamond travel in different directions on adjoining facets because of the stone's directional hardness. Magnified 20×.

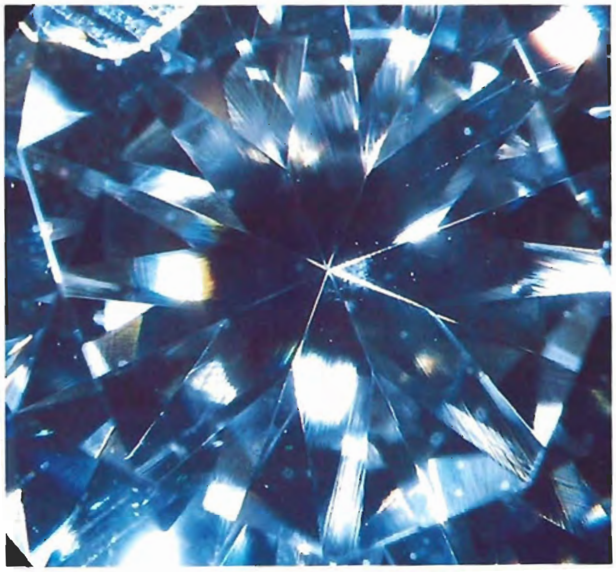


Figure 15. Polishing marks on diamond simulants usually travel in approximately the same direction on adjoining facets. Magnified 20×.

If the material has no inclusions, other tests can render the necessary proof.

Polishing Marks. When examining the stone for inclusions, polishing marks might be noted. Polishing marks are a series of close, parallel lines on the surface of a facet.

Polishing marks are not always seen on diamond because its hardness allows for an excellent polish. If seen, the polishing marks will travel in different directions on adjoining facets (fig. 14). Because of diamond's directional hardness, facets are polished in the direction of the dodecahedral faces.

By contrast, the polishing marks on a diamond simulant will usually travel in approximately the same direction on adjoining facets. The uniform lines indicate a softer material and represent a mechanized process in which the concern of the producers is primarily mass production (fig. 15).

Grain Lines. Straight, parallel lines that might be confused with polishing lines may be the result of graining (fig. 16). Grain lines appear in the direction of twinning, or gliding, and are characteristic of diamond. The lines are usually seen on the surface, but they may also be internal. In addition, graining may take on various shapes (Kane, 1980). Regardless of the form, graining proves the natural origin of the gem material, since only a natural gemstone could exhibit such markings.

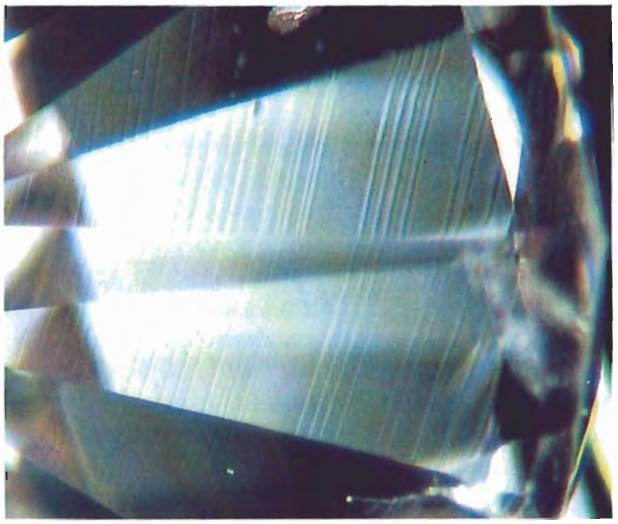


Figure 16. An experienced eye may see grain lines on diamond, which verifies the stone's natural origin. Magnified 35×.

BASIC TESTS TO IDENTIFY THE TYPE OF DIAMOND SIMULANT

If the stone has no distinguishing visual characteristics and positive proof is still wanting, then several tests can be performed to verify the type of diamond simulant. The most important involve specific gravity determinations and special immersion techniques.

Specific Gravity Determinations. Specific gravity is defined as the ratio of the density of one substance to the density of another substance which is used as a standard when both densities are obtained by weighing the substances in air. The determination of specific gravity is extremely helpful since diamond has a much lower value than any diamond simulant on property chart A. Specific gravity is estimated by heft, or by the use of heavy liquids. Precise measurements are obtained on a hydrostatic balance.

Skilled gem identifiers can gauge the density of CZ and GGG in their hands, since GGG's density is twice that of diamond and CZ's density is over one-and-one-half times greater than that of diamond. The diamond simulants that feel closest in density to diamond—YAG and possibly strontium titanate—can be distinguished on the basis of the visual characteristics described above.

Heavy liquids can also help approximate specific gravity. Simply drop the stone in question in methylene iodide (density of 3.32) and note the rate at which the stone sinks. Diamond will sink much more slowly than any of its simulants. It appears to float to the bottom, while the diamond simulants plummet. If a known diamond is not available, the rate of sinking can be compared using a synthetic corundum (specific gravity of 4.00). All the diamond simulants in property chart A will sink faster than synthetic corundum. The use of methylene iodide will at least prove whether a stone is a diamond. A set of comparison stones can be used to help identify the specific diamond simulant.

An accurate specific-gravity measurement can be accomplished by a direct weighing method in which the stone is weighed first in air and then in water to determine the weight lost in water. The specific gravity is found by dividing the material's weight in air by the loss of weight in water. The stones can be weighed on a diamond balance that has been adapted for hydrostatic measurements. The results prove the identity of the material, although the measurements are not as accurate for stones under one carat.

Relationship of Specific Gravity to Size. The higher the specific gravity of a stone, the smaller the stone is per carat, and vice versa. Thus, since diamond has a lower specific gravity than its simulants, the diamond simulants will all be smaller, per carat, than diamond.

TABLE 1. Relationship of specific gravity to size in diamond and cubic zirconia.

Carat weight	Diameter	
	Diamond	Cubic Zirconia
1	6.5 mm	5.5 mm
2	8.2 mm	7.0 mm
5	11.1 mm	9.5 mm

When the stones in question are round brilliants, the relationship can be charted as shown in table 1. Two variables are needed for each stone: the diameter and the weight. When a diamond and a diamond simulant weigh the same, each will possess a different diameter; conversely, a diamond and a diamond simulant with the same diameter will not weigh the same. The figures may not work perfectly, but they will point to the identity of the material.

Immersion Techniques. B. W. Anderson has guided gemologists to a new technique for identifying diamond simulants. Initially, he discovered that diamond simulants have different degrees of visibility when placed table-down in immersion liquid. Stones with refractive indices greater than that of the liquid appear to have dark borders around the girdle and light facet edges, while stones with refractive indices lower than that of the liquid have light borders around the girdle and dark facet junctions. These differences in relief are best seen when the cut stones are immersed in 3.32 liquid table-down in a glass-bottomed cell that is strain-free. The cell should be slightly above its resting surface with light placed directly over the stones.

Interestingly, not only do the majority of the diamond simulants have dark borders when immersed in heavy liquid, but as their refractive indices increase, the width and darkness of the ring around the girdle also appear to increase. Thus, as mentioned earlier, if the diamond simulants were aligned according to refractive index, YAG would have the lowest relief, since its refractive index is closest to that of the liquid, with GGG, CZ, strontium titanate, and diamond (in that or-

Figure 17. The higher the refractive index of the stone, the more distinct the stone is when immersed in methylene iodide and the darker and wider the shadow around the girdle is. Left to right (high to low R.I.): diamond, strontium titanate, CZ, GGG, YAG.

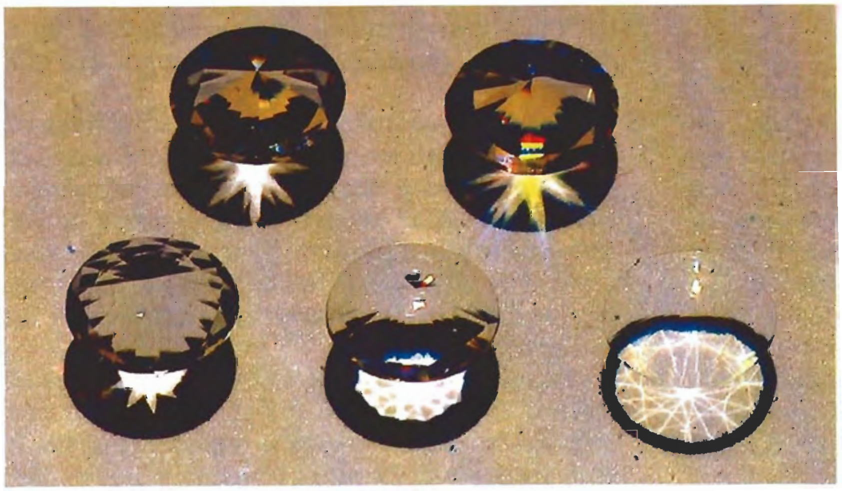


Figure 18. When light is placed over stones immersed in methylene iodide, each stone shows a different reflection pattern. Top row (left to right): diamond, strontium titanate. Bottom row: CZ, GGG, YAG.

der) demonstrating increasing levels of relief (see fig. 17).

Since relief in itself usually will not lead to the specific identity of the gem material, a new application of the Anderson principle has been developed to provide this information. The technique is the same; that is, the stones are immersed in a glass cell and a light is placed overhead. However, the stones are viewed from the side instead of from directly overhead. Viewed at a 45° angle from the resting surface, different stones will exhibit different reflection patterns (fig. 18). While viewing contact photographs of immersed stones, Anderson noted the differing reflections, but he did not specifically apply the principle to the identification of diamond simulants (Anderson, 1971, p. 35). Careful study has shown, however, that when two or more diamond simulants of the same cut are compared, each has a unique reflection pattern. Round brilliants with good proportions seem to provide the best results.

The reflection patterns of diamond and strontium titanate are similar in that they both exhibit bright rays that radiate from the middle of the stone and extend beyond the girdle outline. However, the rays in strontium titanate show spectral colors as a result of the material's great dispersion and usually extend a bit farther than those of diamond.

CZ has a dark area round the girdle, but it is not circularly defined. The middle of its pattern is bright like that of GGG, but contains distinctive sharp, star-like images that extend halfway into the dark area. The reflection pattern of GGG is doughnut-like, with a thick, dark girdle border and a bright interior in which the facet edges are light but somewhat rounded and blurry. The reflection pattern of YAG is characterized by a comparatively thin, dark girdle border and bright facet edges.

In most instances, the reflection pattern will identify the diamond simulant. Since GGG and zircon have similar patterns, the optic character of the stone should be checked before it is immersed. In addition, the patterns may be affected by the distance between the light source and the stone as well as by the distance between the cell and its resting place. If a penlight is used to create the pattern, the optimum distance between the light source and the stone is approximately three-quarters of an inch, and between the cell and its resting place is approximately one-quarter of an inch.

Lately, we have noticed that these reflection patterns can be revealed without immersing the stone. The ramifications of this technique are being studied to see if it can be applied to mounted goods.

Fluorescence. Fluorescence is useful only as a supplemental test in gem identification, since the fluorescence of the diamond simulants is not very constant. It may be helpful, though, to note whether the fluorescent reaction is stronger under long-wave or short-wave ultraviolet light. Diamond generally fluoresces stronger under long wave than under short wave, while most simulants fluoresce stronger under short wave.

The characteristic fluorescence of diamond is weak to strong blue under long- or short-wave ultraviolet light. However, it may be inert or fluoresce a variety of other colors.

GGG's typical fluorescence is a moderate to strong orange (or pinkish orange) under short-wave ultraviolet light. The fluorescence is generally constant, although some stones have been inert.

The fluorescence of CZ is variable. When the material first appeared on the market, the typical fluorescence was orange under long-wave ultraviolet light and yellow or greenish yellow under short-wave ultraviolet light. It has since been shown that CZ may be inert or may fluoresce a number of other colors.

YAG and strontium titanate are usually inert, although YAG has been known to fluoresce a weak orange. Because of its inconsistency, fluorescence should be used only in conjunction with other tests. Chemical impurities, foreign materials, and strain may alter the typical fluorescence of a stone.

INSTRUMENTS THAT SEPARATE DIAMOND FROM DIAMOND SIMULANTS IN MOUNTED GOODS

If the gemstone is mounted, or if a person has not been trained to use the above tests, instruments are available to separate diamond from its simulants. The results do not identify the simulant, but they are very useful at the repair or take-in counter to determine whether or not the stone in question is a simulant. The two most conclusive instruments are the GEM Diamond Pen (Gem Instruments Corp., Santa Monica, CA) and the diamond probe.

GEM Diamond Pen. The GEM Diamond Pen effectively separates diamond from the above simulants on the basis of diamond's unique surface tension. Surface tension refers to the ease with which a loose diamond can be picked up by a damp finger; most simulants do not possess this property.

The effects of surface tension are illustrated by placing a small drop of liquid on the surfaces of a diamond and a diamond simulant simultaneously. The liquid spreads on the surface of the diamond, while it beads on the surface of the simulant. The GEM Diamond Pen uses a nondrying colored liquid to demonstrate the property quickly and easily.

To ensure an accurate test, the stone's surface should be well polished and clean. Hold the pen perpendicular to the testing surface. In a quick even stroke, run the tip of the pen across the surface. In this position, the pen will allow only a metered amount of liquid to flow. A common mistake is to hold the instrument in the same position as a writing pen, in which case too much liquid is deposited on the surface.

Magnification may be needed to examine the drop of liquid. The reaction may be affected by abrasions or coatings on the surface, which can be removed by a polishing compound included in the GEM Diamond Pen kit. In addition, a diamond doublet would fool the pen unless surfaces on both the crown and pavilion were checked. However, the test can be performed on both loose and mounted goods and, if used properly, provides positive proof of diamond.

Diamond Probe. The diamond probe yields the fastest, most consistent results as to whether the material is diamond. Unlike the Diamond Pen, it is based on a bulk property that is not subject to miscalculations. The probe measures the thermal conductivity of diamond. Diamond's ability to conduct heat is greater than that of any known simulant, as evidenced by the fact that diamonds are colder to the touch than any simulant and become warm more quickly when worn. Similarly, moist breath evaporates much more quickly on a diamond.

A typical thermal conductivity unit consists of a small box with a pen-like probe attached to the unit by a cord. The only requirements for the use of the unit is that the stone be at room temperature and that the probe pen be held perpendicular to the testing surface. Position the pen, push lightly, and note the reaction. If the tip of the probe touches a diamond, the needle on the scale points to "diamond"; if it touches a diamond simulant, the needle points to the "simulant" area.

The diamond probe cannot distinguish among all diamond simulants because they do not all differ significantly in their ability to conduct heat. Some of the recently marketed probes have indicator marks for the important simulants; however, YAG and GGG are generally too close to separate.

If the machine is working properly, it is impossible to mistake diamond. To ensure that the machine is operating properly, press the tip of the probe against one of the check areas, or compare reactions with known stones. Thin coatings on the stone's surface should not affect the readings. Only a diamond doublet can confuse the machine. The results have been found to be accurate for both loose and mounted stones.

CONCLUSION

There is no good reason to misidentify a diamond. Visual characteristics alone should reveal a simulant, and they may lead to the precise identity of the material at hand. If the visual characteristics are not satisfactory, an estimate of specific gravity coupled with the visual traits will often separate diamond from its imitators.

If a specific identification is needed, hydrostatic measurements can provide the proof, or the B. W. Anderson reflection technique will identify simulants that are cut to certain proportions.

Last, the Diamond Pen and diamond probe conclusively identify a loose or mounted diamond. Even if the visual characteristics are obstructed, and the stones cannot be weighed or immersed, these instruments will reassure the gem identifier. At present, no diamond simulant duplicates the optical and physical properties of diamond. Until synthetic diamond is manufactured for commercial use, if ever, diamond should pose no problem in identification.

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NOTES
· AND ·
NEW TECHNIQUES

THE HIDDEN BEAUTY OF AMBER: NEW LIGHT ON AN OLD SUBJECT

By *John I. Koivula*

While many aspects of the nature of amber and its organic inclusions have been reported in the literature, virtually nothing has been recorded about the inorganic—mineral, liquid, and gas—inclusions "hidden" amid the better-documented life forms. This article takes a microscopic look at the gas bubbles and crystal forms that also belong to amber's inner world. With the use of polarized light, the author also documents strain centers in the amber, including movements made millions of years ago by animals trapped in the resin.

The gemological literature is filled with a wealth of information on amber and its inclusions. Seemingly countless and exhaustive studies on the subject have been carried out by well-qualified, highly skilled paleozoologists, paleobotanists, and gemologists. Their keen observations have led to the identification of thousands of varieties of flora and fauna as inclusions in amber, and more will undoubtedly be discovered as the search continues. Through the application of infrared spectrophotometry and other sophisticated instrumentation (Langenheim, 1964), the very origins of the amber resin itself are now being studied.

Consequently, when we scan the available literature, it seems that there is very little that remains to be written on the subject of amber. But, to the close and careful observer, amid the often-noted inclusions of flowers and insects a world of hidden beauty unfolds, a microscopic world never before reported in the gemology literature.

This journey into amber's hidden microscopic world begins with a simple spherical void, a bubble. Anyone who has studied amber under the microscope has seen bubbles suspended in its golden depths. But the microscopist's eye is usually drawn away from any bubbles present to the more captivating inclusions of flora and fauna. In fact, if a piece of amber does not contain insects or other fossilized life forms, it is seldom given a second glance with the microscope. This singular fixation on life forms has kept an intriguing portion of amber's inclusion world from the gemological community.

At first glance, except for minor differences in shape, the bubbles found in amber appear to be essentially the same. However, careful study under the microscope reveals that many have unique characteristics. Figure 1 shows a gas bubble distorted by the flow of the resin before it solidified. The bubble plays host to a transparent euhedral crystal of an unknown solid, possibly quartz (Flamini et al., 1975). Figure 2 shows a group of white crystals that appear to adhere to the lower-front inner surface of this somewhat spherical bubble. The crystal group subsequently moved to the inner-back surface of the bubble, revealing it-

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If the readers of this paper have observed any seemingly unusual inclusions in amber, the author would be delighted to hear of them.

Figure 1. Distorted by the flowing motion of its amber host, this bubble is unique in that it contains a well-formed crystal, possibly quartz. Magnified 65×, dark-field illumination.

self as a mobile solid. The photomicrograph of a bubble in figure 3 illustrates a three-phase inclusion in amber. The solid phase consists of tiny brownish-red pollen grains. The largest of these appear to be attached to the inner surface of the bubble, while the smaller grains move around inside the bubble chamber, propelled by heat-convection currents and water vapor. The liquid phase is a droplet of ancient rain or dew. It can be seen easily in various stages of condensation on the inner surface of the gas bubble, the third phase.

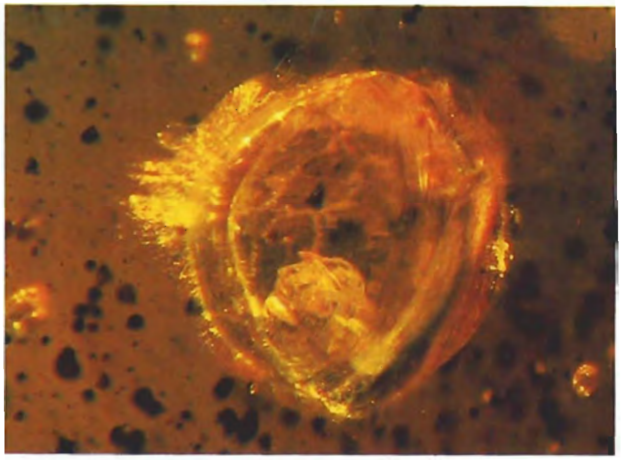

Figure 2. This gas bubble contains a group of whitish crystals that appears to be sticking to the bubble's lower front surface but revealed itself as a mobile solid. Magnified 40×, oblique illumination.

It is an established fact that the physical bodies of all animal life are composed primarily of water. When insects or other fauna are trapped in amber, their internal organs deteriorate, leaving behind the fossilized exoskeleton. Transparent, gem-quality amber is not porous, so any organic body fluids trapped within the insect's remains are left behind in the exoskeletal void. If the exoskeletal shell is thin enough to allow the passage of light, then a small mobile gas bubble often can be observed rolling about inside the fauna host. In figure 4, we see one of these mobile bubbles trapped in the abdomen of an ant. Occasionally, small fragments of the exoskeleton will float with the bubble, creating a three-phase inclusion.

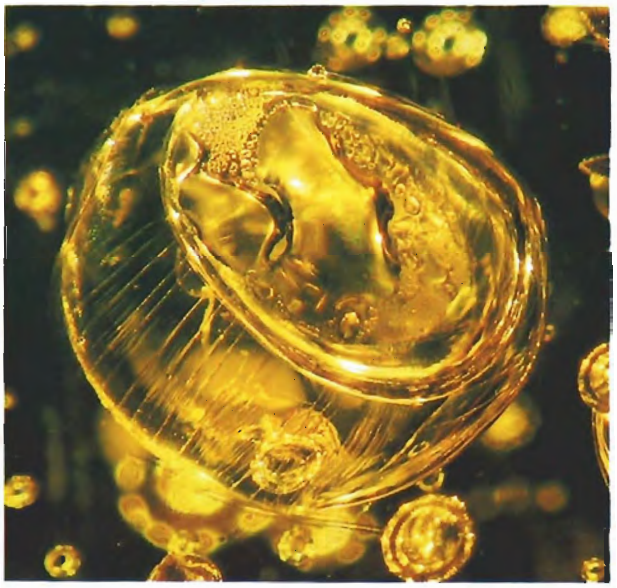

Figure 3. The solid phase of this three-phase inclusion in amber consists of microscopic pollen grains, some of which stick to the inner surface of the void while others fly around. The liquid phase, seen here in various stages of condensation on the inner surface of the gas bubble, is possibly a droplet of ancient rain or dew. Magnified 40×, dark-field illumination.

The application of polarized light to the study of amber reveals further heretofore hidden details. The spherical voids shown in the first photo in figure 5 house two-phase, liquid and gas, inclusions with a mobile gas phase in each. Under polarized light, framed by bright interference colors, these inclusions show themselves as strain centers in the amber. A close-up of a strain-center

Figure 4. The internal organs of this ant in amber have deteriorated, and only the body fluids remain in the exoskeleton. A bubble of abdominal gas can be seen floating about. Magnified 30×, dark-field illumination.

liquid-and-gas two-phase inclusion shows tiny liquid droplets that have condensed in the gas phase as a result of temperature-change and vapor-pressure alteration.

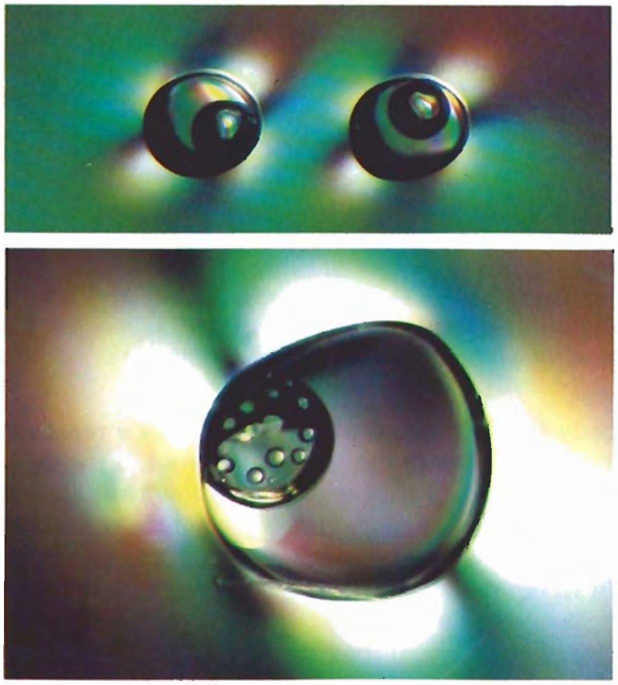

Figure 5. The bubbles in the top photomicrograph house two-phase, liquid and gas, inclusions with mobile gas phases. Under polarized light, these inclusions show themselves to be strain centers in the amber. Magnified 35×. Higher magnification reveals tiny liquid droplets that have condensed in the gas phase as a result of vapor-pressure alteration. Magnified 60×.

Figure 6. The death dance of three tiny bees. The final life movements of arthropods are often traced in amber, but only under polarized light do these final death throes become visible as vivid strain colors. Magnified 10×.

Polarized light may also disclose "hidden" details in amber's fauna inclusions that often remain invisible when other methods of illumination, such as dark field, are used. If insects or other fauna are trapped alive by the resin, their final life movements—as they attempted to escape—are visible under polarized light in the form of vivid strain colors surrounding their bodies and legs. Figure 6 illustrates the death dance of three small bees.

A case of not seeing the forest for the trees. It is obvious that there is more to amber than has previously met the gemologist's eye. These newly recorded facts only add to the unique nature of amber as a gem material.

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ARTIFICIALLY INDUCED COLOR IN AMETHYST-CITRINE QUARTZ

By Kurt Nassau

Adjacent amethyst and citrine colors in the same crystal of quartz have been reported from South America, although there appears to be uncertainty as to the exact locality of origin. Such material has also been produced by synthesis. Several previous studies on the impurities contained in natural and synthetic quartz and the effects of irradiation and heating, as well as new heating and irradiation experiments with the current natural amethyst-citrine quartz and with amethyst, are described. It is concluded that there are presently no known tests to distinguish natural bicolor material that was heated or irradiated (or both) in nature from natural amethyst heated or irradiated (or both) by man or from the equivalent synthetic material.

Figure 1. Natural amethyst-citrine quartz, 108.5 carats (from the Los Angeles County Museum of Natural History collection).

A new and rather unusual gem material has been reported recently, namely, the occurrence of citrine and amethyst colors side by side in the same crystal of quartz. Brief descriptions have been given by Hehar (1980), Koivula (1980), and Vargas and Vargas (1980). The locality was originally reported as being in the Rio Grande do Sul mining area of Brazil, close to the Uruguay border, or in northern Uruguay itself; subsequently it has been reported to be in Bolivia (G. Vargas and J. Koivula, personal communications). The names *amethyst-citrine quartz, citrine-amethyst quartz, ametrine, trystine,* and *golden amethyst* have been used for this material. The first of these is a clear and descriptive designation and will be used below. The well-cut stone shown in figure 1 clearly displays both colors.

Usually, a gemstone material is synthesized after naturally occurring material provides the stimulus for duplication attempts. In this instance, however, the author has had a piece of *synthetic amethyst-citrine quartz* in his possession for several years without realizing its significance! This unusual specimen is shown in figure 2, where the purple amethyst and yellow citrine colors can be clearly seen.

A general description of the growth of synthetic quartz has been given by the author (Nassau, 1980a and 1980b). The causes of color in quartz have been reviewed by Nassau and Prescott (1977). Briefly, citrine and amethyst are caused by the incorporation into quartz of different types of iron; amethyst also involves irradiation. The amounts of the two types of iron present in a quartz crystal depend on the growth direction and on other growth factors, but either type may be present by itself or they may both be present in variable ratios. It has long been known that the depths of the colors do not correlate with the analyzed iron concentration; this is a result of the presence of a third type of iron, which is not color producing.

Many scientific studies have also been conducted over the years on the impurities contained in natural and synthetic quartz, together with the effects of irradiation and heating (Cox, 1977;

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The author wishes to thank Mr. Glenn Vargas of Thermal, CA, for supplying amethyst-citrine quartz, and Mr. J. I. Koivula and Dr. D. V. Manson of the Gemological Institute of America, Santa Monica, CA, for supplying both amethyst-citrine quartz and the sectored amethyst sections.

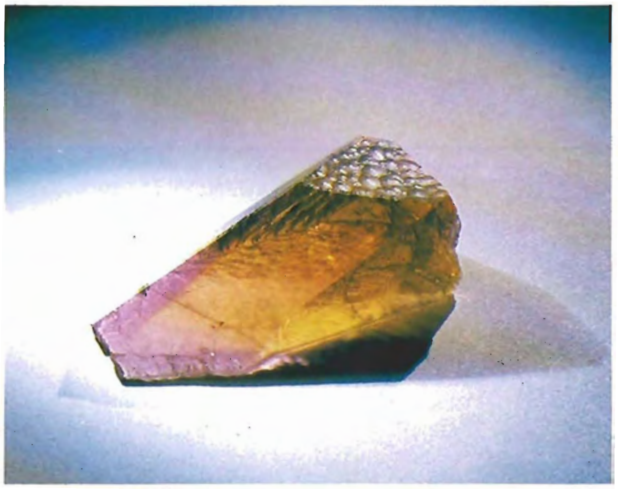

Figure 2. Synthetic amethyst-citrine quartz crystal, 3 cm long (author's collection).

Cohen and Hassan, 1974; Hassan, 1972; Cohen, 1975; Lehmann, 1975; and Nassau and Prescott, 1977 and 1978). These studies, as well as some current experiments, suggest that several possibilities exist as to the origin of any specific piece of amethyst-citrine quartz.

NATURAL AMETHYST-CITRINE QUARTZ

In their reports, Hehar (1980), Vargas and Vargas (1980), and Koivula (1980) note six alternating regions, three each of amethyst and citrine, which clearly correspond to the major-rhombohedron growth regions of typical amethyst and the minor-rhombohedron growth regions of typical citrine. There are three significantly different ways in which such naturally occurring amethyst-citrine quartz could have been formed. First, it is possible that the quartz simply grew under such conditions that the amethyst-forming iron was incorporated under the major-rhombohedron faces, while only citrine-forming iron entered under the minor-rhombohedron faces (some may, of course, be present under the majors as well). Natural irradiation would then produce this end product.

There are, however, important alternative possibilities involving different mechanisms. In the second suggested mechanism, both amethyst-producing iron and citrine-producing iron are present in all sectors of the quartz, and the naturally occurring irradiation has produced an amethyst color in all sectors. According to the second scheme, the quartz next would have passed through a heating stage that bleached the minor-rhombohedron amethyst to leave citrine, but which did not bleach the major-rhombohedron amethyst material. According to the third scheme, heating could have affected the material in such a way that a subsequent irradiation might have colored only some parts, thus producing the observed end product.

According to these alternative schemes, the important difference is not in the quantities of iron occupying the different sites, (although some such differences may be present), but in the behavior of the material with respect to heating. The determining factor is either the temperature at which the amethysts bleach (i.e., at which the color centers are destroyed) or the temperature of heat treatment after which the citrine can no longer be converted to amethyst. Such differences (e.g., in the bleaching temperatures) do occur in quartz (Nassau and Prescott, 1977), and sectored variation in properties has also been noted in conjunction with the pleochroic anisotropy in smoky quartz color centers (Nassau and Prescott, 1978) and in amethyst (Cox, 1977). There are two questions that arise should one of these schemes apply: (1) Was the heating or irradiation (or both) a naturally occurring event or was it performed by man? and (2) Is this property unique to the locality or will amethyst from other localities produce the same result if suitably treated?

HEATING AND IRRADIATION EXPERIMENTS

Specimens of the natural amethyst-citrine currently in the trade were made available to the author by the very kind cooperation of G. Vargas and by J. I. Koivula and D. V. Manson of the GIA.

Parts of two specimens were irradiated in a cobalt-60 gamma-ray cell to a dose of at least 1,000,000 rads. As a result, portions of some of the amethyst and citrine regions acquired an additional weak smoky tint. Heating to 350°C removed this tint and restored the specimens to their original state.

Parts of two different specimens were next heated in air in a furnace for two-hour periods first at 250°C and then at successively higher temperatures at intervals of 50°C. The amethyst sectors became yellow after the two hours at the 400°C step; the citrine regions were not affected by this heat treatment. A subsequent irradiation followed by heating to 350°C to remove smokiness restored the original amethyst-citrine colors.

In order to obtain comparison data, experiments were also performed on two specimens of sectored amethyst from Minas Gerais, Brazil, which were also obtained from the Gemological Institute of America. These specimens exhibited alternating sectors of dark (major rhombohedron) and pale (minor rhombohedron) amethyst. Duplication of the first irradiation experiment above gave essentially the same results: smoky purple and pale smoky purple, with the smoky component removed and the original state restored upon heating to 350°C.

Heating the sectored amethyst to successively higher temperatures, however, produced an unexpected result: the dark purple sectors became somewhat lighter but the pale purple sectors turned yellow at 400°C. To the eye, this material now had exactly the same appearance as the amethyst-citrine. Subsequent irradiation and heating to 350°C restored the original all-amethyst state. This process corresponds to the second mechanism discussed above, but the end product is unlike the current amethyst-citrine, which did not convert to all-amethyst even after 20 megarads of cobalt-60 gamma rays.

Heating of these same sectored-amethyst sections to the slightly higher temperature of 450°C bleached all the amethyst sectors to yellow. A subsequent irradiation followed by heating to 350°C reproduced not only the appearance of the current amethyst-citrine, but also its behavior with respect to heating and irradiation: it could no longer be returned to all-amethyst. A specimen of this treatment-produced amethyst-citrine (see figure 3) has been returned to the Gemological Institute of America for archival purposes.

Iron analyses were not performed because such analyses cannot distinguish among the three types of iron but only give the total iron present; this total has not provided useful information in previous studies.

DISCUSSION

The above experiments show that the amethyst-citrine combination in quartz can be obtained by heat-treating sectored amethyst from Minas Gerais, Brazil, in either one of two ways: (1) a medium heating step produces the change, but this can be reversed by irradiation; (2) a more intense heating followed by irradiation and a second, gentle heating also produces the change, but the product can no longer be returned to all-amethyst.

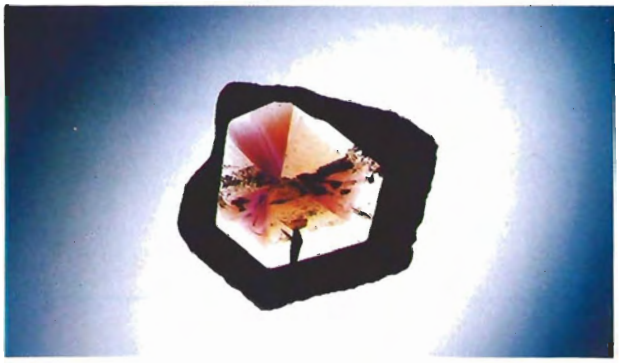

Figure 3. Amethyst-citrine quartz produced by heating and irradiating sectored amethyst from Brazil; 12 mm across.

Since the sectored amethysts tested were merely randomly chosen, it is likely that much such material from a variety of sources can be treated to produce amethyst-citrine, including man-made quartz. There are no known tests to distinguish the origin of color of natural material that was heated/irradiated in nature from natural amethyst heated/irradiated by man or from the equivalent synthetic material.

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Gem Trade LAB NOTES

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A NOTE FROM THE EDITOR

This is the first Gem Trade Lab Notes column under the new format of Gems & Gemology. *Although the general style of the former columns will be retained, a few improvements have been made, including the use of more color photos.*

Previously, there were separate columns for the New York, Los Angeles, and Santa Monica branch labs. It will be my job to combine the information supplied by each branch into one column. The New York correspondent will continue to be Bob Crowningshield, vice president of GIA and director of the colored stone section of the Gem Trade Lab. Bob Kane will keep the data from Los Angeles coming in, while Karin N. Hurwit supplies the items of interest from Santa Monica.

Perhaps the most important long-range improvement is the arrangement of the material in alphabetical order, by variety. Such an arrangement makes it easier to provide an annual index of the stones coming into the labs and aids the reader in his or her search for more information on particular stones.

Please note that all magnifications given refer to the power of the microscope at which the photograph was taken, not necessarily the final magnification of the printed image.

AQUAMARINE

Trapiche Aquamarine?

An unusual stone came into the New York lab for identification. Figure 1 illustrates the green-blue melon-cut drop that appeared at first to be merely a drilled aquamarine bead. In reality, this stone has been cut from a trapiche-like crystal with six separations (apparently carbonaceous) and a clear central hexagonal area, as shown in figure 2. Although the stone displayed evidence of chromium in its absorption spectrum, its color was unlike that of any trapiche emerald crystals we have seen. However, the chalcedony-like translucency and the black inclusions seen in figure 2 do resemble characteristics common to trapiche emerald.

Figure 1. Melon-cut aquamarine, approximately 35 cts.

Figure 2. End view of the melon-cut aquamarine in figure 1. Magnified 10×.

DIAMONDS

Cyclotron-Treated Diamonds

Diamonds were first treated in a cyclotron to produce color nearly 40 years ago. A color then seen somewhat frequently in treated diamonds, but seldom seen today, is a pleasing orange-brown. However, cyclotron treatment, which imparts a shallow penetration of color, is an expensive and troublesome process. For these reasons, other methods of artificially inducing color in diamonds have been developed, including atomic-pile treatment. Atomic-pile treatment penetrates the diamond completely, resulting

Figure 3. Cyclotron-treated diamond. Left = crown facets viewed through the pavilion, magnified 40×. Center = culet area viewed through the table, magnified 30×. Right = culet area and brown graining, magnified 12×.

in even color throughout the stone. This process has largely replaced cyclotron treatment, and we seldom see cyclotron-treated diamonds in the laboratory today.

Several months ago, however, a cyclotron-treated diamond was submitted to the Los Angeles lab for determination of the origin of color. Since the color penetration was shallow, this particular diamond did not exhibit the usual absorption spectrum with the typical 5920 Å line.

The fact that the color is shallow and confined to a layer near the surface makes cyclotron treatment easily detectable when the stone is examined under magnification. As seen in the three sections of figure 3, this diamond displayed a surface layer of intense color paralleling the edges of facets on the crown and around the culet that is very typical of cyclotron-treatment. The first photo in figure 3 shows crown facets viewed from the pavilion. The area around the culet is seen in figure 3 center as viewed through the table. The final pose in figure 3 shows, at lower magnification, the treatment-layer zone at the culet, as well as brown graining.

It should be noted that natural-color diamonds frequently display brown graining. Light brown diamonds with brown graining are sometimes treated to darken their color and thus improve their appearance; the graining, of course, is still present.

A dark blue-green diamond examined in both California and New York appeared watery when viewed from the side, which suggested that it was surface treated. However, it did not show the umbrella around the culet or dark penetration zone around the table and star facets which are typical of such treatment. Finally, with immersion and later in air we were able to determine that the stone was treated on one side of the pavilion only, where a grid-like penetration zone appeared when the diamond was viewed through the upper girdle and bezel facets (see figure 4). We have heard that in the early days of cyclotron treatment if a stone fell from its fire-resistant holder, operating procedures did not allow stopping the equipment to right it. It is rumored that just such an accident led to the discovery that overexposed dark green stones could be heated to turn them brown, orange, or yellow.

Figure 4. Grid-like color zoning in a cyclotron-treated diamond. Magnified 40×.

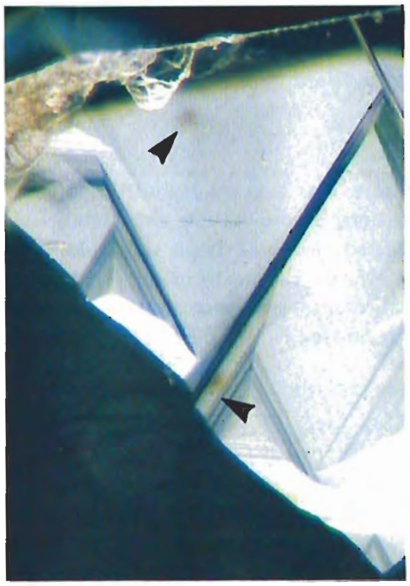

Figure 5. Radiation stains on a natural of a near-colorless diamond (see arrows). Magnified 45×.

Natural Radiation Stains

Radiation stains on diamond naturals are often associated with green stones, but they can occur on diamonds of any color. In the Fall 1979 issue of *Gems & Gemology*, we mentioned a G-color round brilliant with radiation stains on both of the two naturals. Since that time, we have seen several diamonds, not green, that had this feature. Figure 5 shows a near-colorless diamond with two such small brown stains on a natural. Another diamond, of M to N range in color, was also observed to have a stain on a natural. Directly across from the natural

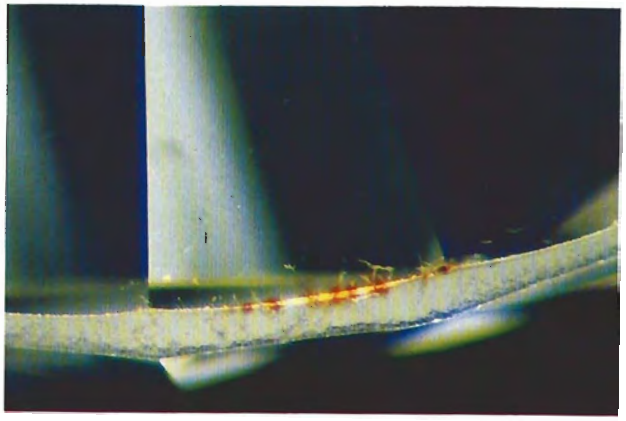

Figure 6. Radiation stain in a diamond natural. Magnified 50×.

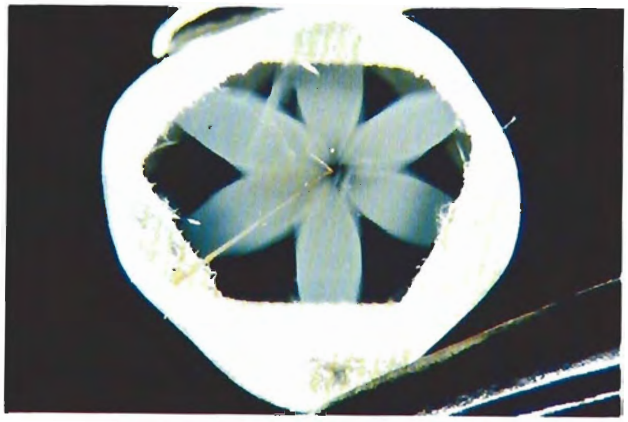

Figure 7. Flower-like inclusion in a diamond. Magnified 15×.

there was a stain remaining in the bruted girdle where the rough diamond skin had been removed. The stain in the natural is intense in color and penetrates deep into the stone (see figure 6).

Inclusions

The cover of the Spring 1952 issue of *Gems & Gemology* featured a windowed diamond crystal with a beautiful flower-like inclusion that shows both petals and sepals. This year we were shown a similarly windowed crystal with a flower-like inclusion that has a brown tubule which looks ever so much like a stem or the stick for a pinwheel (see figure 7).

Figure 9. A uniquely glassy diamond natural. Magnified 35×.

Figure 8. Irregular tube-like inclusions in a diamond. Magnified 18×.

We are at a loss to explain the unusual inclusions in the round-brilliant cut diamond shown in figure 8. On examination under the microscope, they appeared to be hollow tubules, some brown or filled with a brown material.

An Unusual Natural

The unique natural on a diamond brought into the Santa Monica lab warrants a description. The surface of this natural was very smooth and glass-like (see figure 9), almost as if it had melted! There was absolutely no evidence of any growth or etch marks on the surface of the natural. No one in the Gem Trade Lab remembers ever before seeing a diamond natural with this appearance.

Notes on Diamond Cutting

We admire the cutter of the orange cube diamond seen recently in New York (see figure 10). Gem-quality cube-shaped diamond crystals are almost unknown, so in retaining the cube shape with very symmetrical beveling of the edges the cutter has

Figure 10. Cube-cut diamond, 1.13 cts.

Figure 11. Top view of a Peruzzi-cut diamond, 2.00 cts.

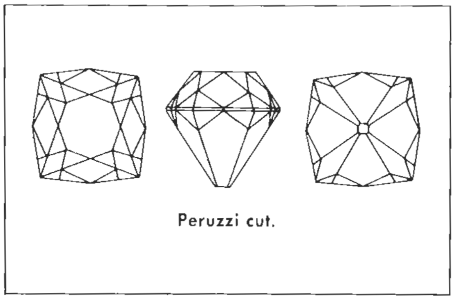

Figure 12. Diagram of the Peruzzi cut. (Diagram courtesy of Robert A. P. Gaal, Diamond Dictionary, *2nd ed., Gemological Institute of America, Santa Monica, CA, 1977.)*

captured the stone's beauty and rarity.

Rare outside museums or royal collections are Peruzzi-cut diamonds. We were privileged to receive for grading and photographing such a stone weighing more than 2.00 cts. (see figure 11). Presumably this style of cutting, detailed in figure 12, was first employed by a Venetian cutter in the 17th century, and it led to the old-mine cut, the old-European cut, and finally the modern brilliant. The stone we graded had no culet, had a table percentage of 46, and showed a depth percentage of 97.9.

II$_B$ or Not II$_B$

Type I diamonds are opaque to short-wave ultraviolet (UV) light, while type II are transparent. Type II$_A$ diamonds are not electroconductive, but type II$_B$ are. Normally we check for a type II diamond in the darkroom, using short-wave ultraviolet light and a piece of scheelite placed behind a porthole. Only UV light that has passed through the stone can affect the scheelite. If the scheelite glows, we test the stone further for electroconductivity to determine whether it is type II$_B$. Of course, there is no permanent record of these UV transparency tests. To obtain a permanent record, place the stones table down on the emulsion side of photographic paper and expose them for a very short time (two seconds) with the ultraviolet lamp perhaps a foot away. Figure 13 shows the transparency difference between a type I yellowish marquise and a type II$_A$ pear-shaped diamond.

Figure 13. Ultraviolet transparency of a type I marquise compared to a type II pear-shaped diamond.

EMERALD

An emerald sent to Santa Monica for identification showed quite unusual structural characteristics. First, we were surprised to see a significant difference in transparency when the stone was viewed from different angles. As we looked at the stone through the table, the emerald was almost transparent; yet when we looked sideways at the pavilion facets, the stone was only translucent, having the appearance of dyed green chalcedony. Magnification of this stone revealed a peculiar structure: straight, colored growth lines were crossed by lightly curved, wave-like bands (see figure 14). The stone was of natural origin, possibly cut from a trapiche-type crystal.

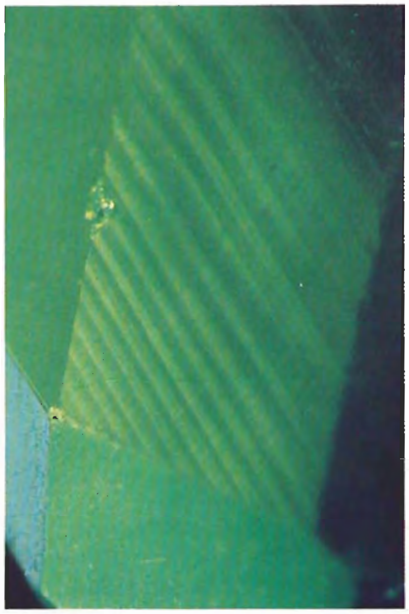

Figure 14. Unusual growth lines in an emerald. Magnified 63×.

The New York lab encountered a synthetic emerald, reportedly of Russian manufacture, with a refractive index of 1.560–1.563 and a low specific gravity. The stone transmitted red on the spectroscope light but showed only weak long-wave ultraviolet fluorescence. The stone had fairly typical flux fingerprints and even contained a platinum crystal in the girdle. What was particularly unusual was the presence of long needles, which we have always felt indicated natural origin. Nearly as disturbing was the discovery of a cavity filled with yellow liquid in this otherwise obviously synthetic emerald (see figure 15). Elsewhere in the stone, the "Venetian blind" banding that is typical of a synthetic was visible (fig. 16).

MALACHITE

A malachite carving of an oriental lady holding a flower basket was sent to the laboratory for a damage report. Part of the flower basket and the right hand of the lady had been broken off, leaving a surface remarkably like a cleavage that astonished us (see figure 17). Although malachite has one perfect cleavage direction, massive material usually does not show it. What had happened? This particular piece of malachite apparently was formed by the process of sedimentation. When the carving was damaged, the separation occurred between bedding planes in the stone and produced a flat, smooth break.

Figure 15. Yellow inclusion in a synthetic emerald. Magnified 25×.

Figure 16. "Venetian blind" banding in synthetic emerald. Magnified 10×.

Figure 17. Damaged malachite carving showing separation between bedding planes; 2.5 cm × 7.5 cm × 10.5 cm high.

PEARLS, Cultured

The Santa Monica lab had the opportunity to examine a necklace consisting of bluish-gray cultured pearls with one "oddball" in the strand. The layered structure of shell was apparent in this single bead (see figure 18). Notice also the concentration of dye at the drill hole. It would seem that at one time this pearl was crushed or received a blow that caused the nacreous outer layer to fall off, exposing the nucleus.

A "faith-shaker" was a pair of earrings set with a bronzy-black, drop-shaped pearl and a similarly shaped white pearl. Both were cultured. However, the black pearl fluoresced reddish brown—much stronger than any known Tahiti black cultured pearl we have seen. The history of the earrings precluded the possibility that the black pearl could have been cultured in Tahiti waters. Incidentally, it is reported that a much wider range of hues has been produced in the current harvest there, so we may see colors other than the usual black, dark gray, and light gray.

Figure 19 illustrates a necklace set with bronzy-colored dyed cultured pearls. The shapes too are unusual.

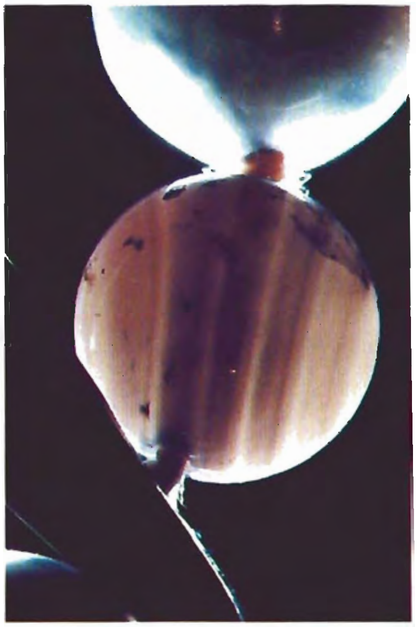

Figure 18. Shell nucleus of a cultured pearl. Magnified 10×.

Figure 19. Necklace of unusual bronze-colored dyed cultured pearls.

RUBY

Synthetic stones examined in the New York laboratory recently have been cause for alarm. The first was a flux-grown synthetic ruby reportedly of recent Chatham manufacture. It weighed more than 5 cts. and had fine flux fingerprints fairly well distributed with only one area of typical coarse flux. The alarming characteristic was angular, silk-like banding visible to the unaided eye (see figure 20). Individual needles could not be discerned; rather, we observed precisely the effect we have seen when a Burma star ruby has been heat treated and the rutile needles are not quite absorbed. Mounted, it could readily be misidentified, since the silk-like bands are not expected in synthetic stones. The stone was highly fluorescent and was obviously not cut in the Orient. Whether this stone indicates a change in the Chatham product or a one-time "fluke" has not been established.

Figure 20. Angular banding in a flux-grown synthetic ruby. Magnified 30×.

We have mentioned previously the process whereby ordinary synthetic blue sapphires are heated in crucibles with an unknown liquid that is then incorporated within induced fractures to produce very believable fingerprint inclusions. It was therefore more expected than alarming to receive for identification a synthetic Verneuil ruby showing both curved striae and "fingerprints" (see figure 21).

Figure 21. Curved striae and "fingerprint" inclusions in synthetic ruby. Magnified 30×.

SAPPHIRES

Induced Surface Coloration of Natural Sapphires

The shortage of Sri Lankan sapphire rough suitable for heat treatment in Bangkok has evidently led to the use of cut stones that are heated after packing in chemicals to diffuse color into the surface. The method reportedly is a variation of the one outlined in U.S. Patent 3,897,529, issued to Union Carbide Corp. in 1975. We first encountered such stones a year ago in the form of an orange sapphire, reported in the Fall 1979 issue of *Gems & Gemology.* Since then we have seen a number of parcels containing variously colored treated stones.

Under short-wave ultraviolet light, most of the stones treated by induced surface coloration show a patchy fluorescence where the diffused color was removed when repolished. However, a stone sent to New York by the Los Angeles lab did not fluoresce. When the stone was immersed, all facets showed color except the girdle, which had been repolished and all diffused color removed (see figure 22).

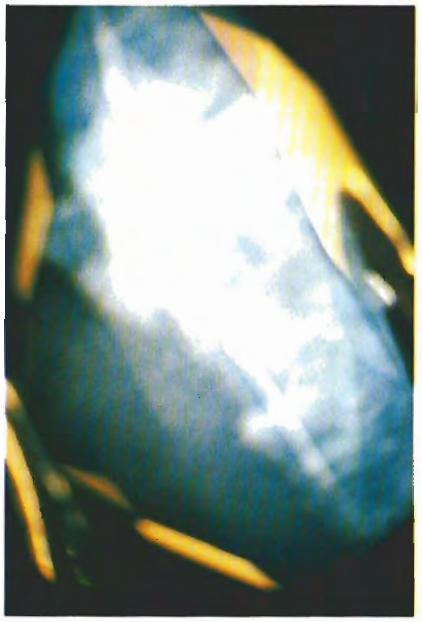

Figure 22. Loss of color in the repolished girdle of a color-treated sapphire. Magnified 10×.

Figure 23. Star spinels. Magnified 10×.

SPINEL

It is not often that one has the opportunity to see a star spinel. Imagine our surprise when two of them arrived at the Santa Monica lab at the same time. We were especially pleased when it was apparent that one of the stones showed a four-ray star, while the other star had six legs (see figure 23).

ACKNOWLEDGMENTS

The photographs in figures 1, 2, 4, 8, 13, and 21 were taken by Bob Crowningshield in New York. Al Roditi, also in New York, took the photographs in figures 7, 10, 11, 15, 16, 19, 20, and 22. Shane McClure of the Gem Trade Lab in Los Angeles did the photography for figure 5, while Bob Kane was responsible for the photos used in figures 3 and 6. The specimens examined in the Santa Monica lab were photographed by John Koivula (figures 9, 14, and 18), Mike Havstad (figure 17), and Chuck Fryer (figure 23).

GEMOLOGICAL ABSTRACTS

Dona M. Dirlam, Editor

COLORED STONES AND ORGANIC MATERIALS

Additional and corraborative data on violet gem scapolite probably from Eastern Africa. B. Jackson, *Journal of Gemmology,* Vol. 17, No. 4, 1980, pp. 235–238.

The author describes a violet gem scapolite, probably from Kenya, that has unusually low refractive indices (1.536–1.541) and density (specific gravity of 2.65), and has the highest sodium content recorded thus far in natural scapolite. All the samples exhibited strong dichroism: violet when viewed parallel to the c-axis and colorless when viewed perpendicular to the c-axis. This orientation may be verified if the stone contains straight, tube-like inclusions that align themselves parallel to the c-axis. All the stones examined contained these inclusions, which sometimes broaden out, resembling cleavages. Given the similarities in color and in optical and physical properties, this material may be confused with amethyst. The two stones can be distinguished, however, on the basis of optic sign (scapolite, negative vs. amethyst, positive). *RSS*

The alexandrite effect in minerals: chrysoberyl, garnet, corundum, fluorite. K. Schmetzer, H. Bank, E. Gübelin, *Neues Jahrbuch für Mineralogie Abhundlangen,* Vol. 138, No. 2, 1980, pp. 147–164.

As Schmetzer, Bank, and Gübelin state in the abstract, the purpose of their study is to determine the conditions required for change of color in various minerals. Following a helpful review of the literature on color-change materials, the experimental details of the absorption spectra and chemical analyses are presented in this comparison of the spectroscopy and chemistry of alexandrite and alexandrite-like minerals.

Most of the paper is devoted to analyzing the results of these experiments for alexandrite and those garnets, corundums, and fluorites that exhibit change of color. Specifically, the authors discuss how the elements present and the location of ions in the crystal structure relate to the absorption spectra and therefore to color.

This section is designed to provide as complete a record as possible of the recent literature on gems and gemology. Articles are selected for abstracting solely at the discretion of the section editor and her reviewers, and space limitations may require that we include only those articles that will be of greatest interest to our readership.

Inquiries for reprints of articles abstracted must be addressed to the author or publisher of the original material.

The reviewer of each article is identified by his or her initials at the end of each abstract. Guest reviewers are identified by their full names.

Lastly, the authors hypothesize from their investigation that four features are characteristic of the absorption spectra of color-change minerals. The first is spectral transparency from 15,000 cm^{-1} to 16,000 cm^{-1} (red area). The second is a strong absorption maximum between 17,300 cm^{-1} and 17,800 cm^{-1} (yellow area). Then another absorption maximum exists between 19,700 cm^{-1} and 21,000 cm^{-1} (green to blue area). Finally, there is a continuous increase in absorption from 21,000 cm^{-1} to the limit of the visible area without additional minima. The authors note further that crystals green in daylight generally change to red in artificial light while bluish-green crystals change to reddish-violet. Figures and tables of the spectral and colorimetric data are included as well as a substantial list of references. *DMD*

Alexandrite-like natural spinel from Sri Lanka. K. Schmetzer and E. Gübelin, *Neues Jahrbuch für Mineralogie Monatshefte,* Vol. 9, 1980, pp. 428–432.

In a continuation of their articles on alexandrite-like minerals, Schmetzer and Gübelin report on the investigation of a 1.87-carat spinel that shows a "remarkable change of colour from violet in daylight to reddish violet in artificial light." Through an analytic and spectroscopic investigation, the authors hoped to verify the four features they have postulated as being characteristic of alexandrite-like materials: transmission in the red area of the spectrum, an absorption maximum in the yellow region, transmission in the blue-green, and an increase in absorption from the blue to the ultraviolet end of the spectrum.

In addition to the normal amounts of Al_2O_3 (aluminum oxide) and MgO (magnesium oxide), the microprobe analysis indicated the presence of FeO (iron oxide), Cr_2O_3 (chromic oxide), and V_2O_3 (vanadium trioxide). The position of the maxima and minima bands in this spinel are different from a typical blue spinel. The authors suggest that the overlapping of the absorption bands of Fe^{+2} (iron) by the spectra of Cr^{+3} (chromium) and V^{+3} (vanadium) produced this displacement.

A diagram is also given which plots chromacity coordinates for daylight and artificial light. The authors conclude that this change-of-color spinel does exhibit the four common spectral features. *DMD*

Amber—the New World's fossil gold. G. O. Poinar, Jr., and F. Agudelo, *Américas,* Vol. 32, No. 10, 1980, pp. 31–41.

After a brief introduction that mentions the classic amber locality of the Baltic Coast and brushes on amber's ancient uses and lore, this article discusses in some detail the fossil resin deposits found in the Americas. It focuses on the amber deposits of the Dominican Republic and Chiapas, Mexico, with additional information on the Canadian amber found at Cedar Lake in Manitoba and the Alaskan amber found along the Ketic River near Point Barrow.

The view that the source of all amber was resin from a particular species of pine is disputed in a short section on the botanical origins of amber. With the use of infrared spectrophotometry, the spectra of amber from various localities were compared with those of modern resins. The authors point out the information that may be gained from the insects and other arthropods, as well as the microorganisms such as nematodes and fungi, that have been discovered in amber. The article concludes with a warning to be on guard against amber substitutes. *JIK*

The causes of color. K. Nassau, *Scientific American,* Vol. 243, No. 4, 1980, pp. 124–154.

In this article, Kurt Nassau gives a rather comprehensive summary of five general color-causing mechanisms that he has subdivided into 14 specific categories. Within this framework, he discusses a wide variety of color phenomena, ranging from the vibrant red of a ruby to the multi-hued iridescence of a common oil slick. The interaction of light with electrons is the unifying theme behind almost all causes of color.

The opening sections of the article relate the energy hierarchy of light to the absorption and emission of radiation by the atomic electrons. Nassau's treatment of the crystal field, molecular orbital, band structure, and physical optical theories contains many interesting examples from the gem and mineral kingdoms. Several large diagrams, plus a few color photographs, supplement the verbal explanations.

Some of the parameters, such as electron volts and the spectroscopic notations, will seem bewildering to the nonscientist, but a full understanding of those details is not necessary for grasping the main ideas. Anyone interested in an in-depth treatment of the origins of color should not miss this excellent article. *BFE*

Connoisseurship in emeralds. B. Zucker, *Connoisseur,* Vol. 204, No. 819, 1980, pp. 52–58.

Benjamin Zucker begins with a short summary of the history and lore of emeralds, from their limited use by the Egyptians and Romans to the discovery by the Spanish of the vast resources held by the Incas in South America. He then comments on the rarity of emeralds, which he feels is related to their unique chemical composition. According to the author, the finest color of emerald is "old-mine" green, a term that is supposedly derived from the color of the stones that were first sent back to Europe by the conquistadors. It is a color he describes as a "deep, intense, velvety, almost blackish shade of green."

The color, commercial potential, and characteristic inclusions for emeralds from the major world sources are presented. According to Mr. Zucker, no source currently compares with Colombia. Sandawana emeralds (Zimbabwe) are often small and have a less intense green, Zambian stones are blackish and often highly included, while Brazilian stones are frequently cracked and oiled. Twenty-one colored photographs present typical emeralds from the various localities as well as illustrate inclusions found in natural and synthetic stones.

Although this article is not complete from a gemologist's point of view, it is a very good introduction to emeralds and could be useful to the gem salesperson. *RSS*

Estudio del material de interés gemológico 'angel stone' (A study of a material of gemological interest—angel stone). J. M. Nogués Carulla, C. de la Fuente Cullell, L. M. Roberdeau, and J. M. Bosch Figueroa, *Gemología,* Vol. 11, No. 41 and 42, 1979, pp. 17–29.

"Angel stone" has been considered attractive and durable enough for use in jewelry. The authors report on a gemological study of the material. Angel stone is microcrystalline, opaque, and pale pink. Its major constituent is the mineral palygorskite, impregnated by amorphous silica. The pink hue derives from manganese in the palygorskite (which can also be grayish, yellowish, or whitish). The sample tested was cryptocrystalline, with no directions or fracture planes. There were no cleavage surfaces or splinters; the fracture was conchoidal.

The study included X-ray diffraction, X-ray fluorescence, thermal analysis, examination under the electron microscope, and hydrostatic weighing. Hardness tests were performed with a photomicroscope. It was concluded that the impregnation of the palygorskite added appreciably to the hardness of angel stone (4.5, as contrasted to palygorskite's 2.0–2.5) as well as to its compaction, rendering it usable as gem material.

For further information on palygorskite, see Christ et al., "Palygorskite: New X-ray Data," *The American Mineralogist,* Vol. 54, Nos. 1 and 2, 1969, pp. 198–205. *SLD*

Explanations of the absorption spectra of natural and synthetic Fe- and Ti-containing corundums. K. Schmetzer and H. Bank, *Neues Jahrbuch für Mineralogie Abhundlangen,* Vol. 139, No. 2, 1980, pp. 216–225.

Schmetzer and Bank examined the effects of heat treatment on the absorption spectra of 154 natural sapphire crystals from corundum localities in 10 different countries. Using three different spectrophotometers to measure absorption spectra, the authors studied the alterations of the absorption spectra and then drew conclusions about the mechanisms and valence of the color-causing transition ions.

While all sapphires show certain absorption bands, they can be divided into two groups based on their infra-red spectra and behavior following heat treatment, which reflects initial growing conditions. Three figures and four tables summarize the results for the two groups before and after heating. The extensive bibliography will also be helpful to the reader. *DMD*

Green opal from Gabanintha Western Australia. R. A. Ball, *Australian Journal of Gemmology,* Vol. 1, No. 3, 1980, pp. 5–7.

Ball reports the occurrence of bright "emerald" green opal at Gabanintha, the principal copper center of the Murchison Goldfield. Noting that the opal is found in quartz associated with copper minerals, Ball suggests that the opal results when olivine that has been converted to serpentine is altered to magnesite and opal through the agency of carbonated water. He concludes that the green color results when opal absorbs copper.

Five photographs are included in the article. It is difficult to appreciate the two hand-specimen photographs because they are in black and white, not color. Ball used three scanning electron micrographs to suggest that the opal is actually in a transition stage between opal and agate, as evidenced by the "distinct agate type banding" shown in the photomicrographs. In the summary, he cites Cassedanne and Cassedanne's (1975) account of the occurrence of green opal in Brazil and questions whether a parallel exists between the two, iron causing the color in Brazil and copper causing the color in Australia. *DMD*

Irradiation-induced colors in gemstones. K. Nassau, *Lapidary Journal,* Vol. 34, No. 8, 1980, pp. 1688–1706.

Dr. Nassau begins by citing the increased availability of irradiation facilities as the primary reason for the trend in artificial color change of this type. He then provides a thorough and understandable explanation of the sources of irradiation, including visible light, ultraviolet light, X-rays, and gamma rays. The discussion also details where each source of irradiation is to be found and how samples are treated. In general, the low-energy rays (X-rays) and those particles that are negatively and positively charged penetrate poorly and subsequently color only the surface layer. More active gamma rays and neutrons penetrate very well, producing uniform coloration. As long as the irradiation used is energetic enough to cause the intended color change, the nature of the source is unimportant. A table summarizing the types of irradiation used to effect color change is supplied.

A color change induced by irradiation is, in most cases, due to the formation of a color center. Once a color center has been bleached, it may usually be returned to its original hue by further irradiation. If, however, the sample was overheated during bleaching, re-creation of the irradiated color is impossible. For example, amethyst that has been heated to citrine may be returned by irradiation to its original color provided the temperature used has not been too great. The stability of a color center to light exposure—i.e., the resistance to fading—is the basis for three groups of irradiation-produced color effects. A fourth irradiation effect, one that does not involve color centers, is also described. The irradiation and bleaching behavior for topaz, tourmaline, beryl, kunzite, and quartz is summarized in a second table.

The article represents a well-organized, up-to-date work on irradiation sources, color-center stability, and how irradiation may be identified. It incorporates several aspects of the large body of research on color and treatment already credited to Dr. Nassau. *PCS*

Ivory—popular but prone to many imitations. G. Brown, *Jeweller Watchmaker & Giftware,* Vol. 65, No. 1, 1980, pp. 22–23.

Australia has not yet invoked trade embargoes on carved ivory, which is very popular there. Its popularity has naturally resulted in sometimes successful efforts to unload imitations on retail jewelers; this article tells how to detect such imitations by visual inspection, hot point, and microscopic examination of thin peelings. Eleven photographs serve to clarify the text. These permit comparison of the "engine-turned" effect of elephant ivory with the surfaces of other animal ivories as well as with those of vegetable ivory and plastic. *FS*

Letter from Europe. B. Sullivan, *Mineralogical Record,* Vol. 11, No. 5, 1980, p. 315.

Nicely formed crystals of pale blue aquamarine are described as coming from near the town of Kunar in the province of Kunar in northeast Afghanistan. The crystals range from one to five inches long and are extremely gemmy, as illustrated by the photograph included, yielding 60%–70% facet rough. Sullivan reports on two interesting examples: one is nearly five inches long and has a three-fourths inch morganite crystal attached at the base; the other has a movable water bubble rarely seen in aquamarine. The mine is now reported to be inactive because of the present political situation in Afghanistan. *SFM*

Notes on the properties and inclusions of garnets from Lapland, Finland. S. Hornytzkyj and K. T. Korhonen, *Journal of Gemmology,* Vol. 17, No. 3, 1980, pp. 153–164.

This article describes the red, gem-quality garnet found in northern Finland. It begins with a discussion of the geology of the area where this mineral is found; the authors have included two full-page maps. The article also covers the physical and optical properties, chemical composition, and inclusions of these garnets. The section on inclusions is illustrated with 11 photographs of the most common inclusions seen in this material.

In all, 157 faceted garnets were studied. Two colors were dominant: brownish red and greyish rose. The average weight was 0.57 ct. The refractive index of this material ranged from 1.764 to 1.792. The specific gravity ranged from 3.92 to 4.17. The authors concluded that the six types of crystal inclusions noted in these garnets were probably rutile, zircon, monazite, actinolite, apatite, and ilmenite. *ET*

Nuggets of island sun. H. E. Rice and P. C. Rice, *Américas,* Vol. 32, No. 10, 1980, pp. 37–41.

This short article offers a brief overview of the budding amber industry in the Dominican Republic. It describes the shops where amber can be purchased and mentions the methods used by local craftsmen to fashion raw amber into polished gems and jewelry. The authors continue with a general description of some types of amber found in the Dominican Republic and of mining methods used to recover the amber. It is interesting to note that although the Dominican Republic deposits are considered to be recent discoveries, large-scale mining was begun in 1949 and the first school for polishing amber was established early in the 1950s.

The article concludes with a summary of how amber was formed and some mention of its inclusions. *JIK*

Royal lavulite discovered. B. Jones, *Rock & Gem,* Vol. 11, No. 1, 1981, pp. 56–59.

"Royal lavulite" is described as a "totally new gemstone that looks like a grape popsicle." More compact than the purple charoite from Russia, lavulite has deeper, richer purple tones and is capable of taking an almost mirror-like polish.

Its exact chemical composition is not yet known, but it is reported to be the mineral leucophoenicite, which has been found in reddish to pink masses at Franklin, New Jersey, and in other metamorphic manganese deposits. The name *royal lavulite* was coined to describe its "superb lavender" color; however, this term may not be in general use.

Lavulite comes from Africa, where it was found during operations at a manganese mine. Unfortunately, because the mining there is done by blasting, much of the lavulite is cracked and broken into smaller pieces. These smaller pieces, however, are often completely solid and up to two inches across. The author describes this material as a solid, opaque mixture of at least two minerals: (1) a very dense black material and (2) the royal lavulite itself. A second type of lavulite occurs as lightly banded masses, similar to malachite.

Lavulite is compact, easy to handle, and has a hardness of about 6 on Mohs scale. It is easily worked with diamond or Carborundum wheels and takes a brilliant polish. *ET*

Tourmaline—liddicoatite. J. Wentling, *Lapidary Journal,* Vol. 34, No. 9, 1980, p. 1918.

Jerry Wentling's enthusiasm for tourmaline led him to a type that is currently found only in certain areas of

Madagascar. Named liddicoatite after GIA's well-known president, this type of tourmaline is found to have an unusually high calcium content. Wentling discusses briefly the locations where liddicoatite has been found, and describes the unusual color zoning that makes this type of tourmaline fascinating. *NPK*

DIAMONDS

Battle lines form on lasering disclosure. H. Huffer, *Jewelers' Circular-Keystone,* Vol. 151, No. 10, 1980, pp. 42–44

Associate Editor Helene Huffer reports on jewelry industry reactions to the most recent position taken by the Jeweler's Vigilance Committee (JVC) on disclosure of laser drilling in diamonds. As proposed in the "Diamond and Gemstone" sections prepared for the Federal Trade Commission as part of the revised Trade Practice Guidelines, lasering need not be disclosed. JVC Diamond Committee Cochairman Leo Kaplan stated that because Indians and Israelis are now lasering mêlée, it would be "too cumbersome" to check each stone.

Huffer interviewed other important leaders in the jewelry industry, including Sydney DeYoung of J.&S.S. DeYoung, GIA's G. Robert Crowningshield, and Robert Mason of J. C. Keppie Co. The impact on the diamond's worth is a key issue. On the one hand, lasering often improves the clarity of a stone, increasing its value hundreds of dollars while the lasering itself costs only $25 to $35; on the other hand, the fact that a diamond has been lasered could make the stone undesirable to some and in most cases reduces its value about 10% from that of a similar stone that hasn't been lasered. Is it ethical not to tell the buyer a stone has been lasered? The controversy over this issue will continue. *RJS*

Editor's Note: The December 1980 issue of JCK reported that the Jeweler's Vigilance Committee has reversed its position, and now recommends that lasering be disclosed.

The diamond market: a new concentration of power. M. Gilbert, *Jewelers' Circular-Keystone,* Vol. 151, No. 9, 1980, pp. 79–90.

Industry Projects Editor Mitchell Gilbert describes in detail new efforts by DeBeers to concentrate power in the diamond market. Every member of the jewelry trade will be affected by the dramatic changes occurring at all levels, from sales and distribution to mining.

A review of the reasons why the cost of rough diamonds is escalating gives insight into the five ways DeBeers obtains 85% of the world's rough production. Three key considerations are upgrading living standards for its black African workers, prolonging the life of its mines, and establishing policies that enable it to do business with any government regardless of the politics of that government.

However, the buying of diamonds for investment purposes and the selling practices of the Soviet Union (which accounts for 20% of world production) are causing DeBeers to take additional steps to "restore order to the diamond world." To circumvent the impact that investor disenchantment could have on market stability, DeBeers is striving for greater concentration of power, which clearly includes cutting and polishing as well as advertising and sales. Technological developments supported by DeBeers in sawing, cleaving, bruting, and polishing have generated the greatest amount of negative response from some of the traditional diamond leaders. Similarly, they question the direction DeBeers is taking through its subsidaries and "cooperative, efficient companies" in the distribution and sale of polished diamonds. Clearly, the greatest impact of this will be on the smaller business people, whether cutters, middle-level dealers, or independent jewelers. *RJS*

Some very important but little known historic diamonds. E. B. Tiffany, *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* Vol. 29, No. 1 and 2, 1980, pp. 71–78.

Mr. Tiffany briefly outlines several of history's most famous diamonds, and compares them with some obscure yet noteworthy stones. Citing diamonds from such places as Iran, the Soviet Union, and India, Tiffany suggests that many of these "unknowns" have been hidden away in private collections or discovered too recently to gain public notoriety. Sixteen pictures of stones from the Iranian Crown Jewels and the Soviet Diamond Fund are included together with descriptions of their color and weight. *NPK*

A visit to a diamond mine, I and II. H. Hurst, *Modern Jeweler,* Vol. 79, No. 9, 1980, pp. 10–59 and No. 10, 1980, pp. 16–48.

For those who have never visited an actual diamond mine, this brief but interesting "tour" in Kimberley, South Africa, makes enjoyable reading. The color photos included in the article give one a glimpse of the modern technology now used in these operations, somewhat resembling the mining of coal, copper, or limestone. Hurst also describes the Pan Plant, where the crushed blueground is processed. It is noteworthy that X-ray sorters, which use the natural fluorescence of diamonds, are part of the recovery. We are reminded of the mystique, wonders, and hopes of diamond mining by the story of how the finder of a 616-carat diamond received $20,000 plus a new house from DeBeers as a reward and incentive to find more like that one—it should happen to all of us! *GR*

GEM INSTRUMENTS AND TECHNIQUES

Application of multi-purpose spectrophotometer and X-ray fluorescence analysis to distinguish natural and synthetic alexandrites (in Japanese). N. Horiuchi, *Journal of the Gemmological Society of Japan*, Vol. 6, No. 3, 1979, pp. 77–80.

Inviting reader comments and contribution to his continuing research, author Nobuo Horiuchi of the Central Gem Laboratory, Ueno, Taito-ku, Tokyo, contends that with the emergence of sophisticated synthetics and new natural gem sources, the multipurpose spectrophotometer together with X-ray fluorescence analysis can offer a new means of distinguishing alexandrite (chrysoberyl) originating in different localities (Manyara, Tanzania; Bahia, Brazil; Tokowaya, Russia) from its synthetic counterparts (flux alexandrite from both Kyoto Ceramic Co. and Creative Crystal Co.) Horiuchi does not comment extensively on K. Nassau's Czochralski alexandrite, although its properties are presented in chart form along with those of the stones listed above. The author details the physical and optical properties of the natural and the synthetic alexandrites to facilitate comparison and to emphasize the need for a spectrophotometer and X-ray fluorescence analysis in identification.

With the multipurpose spectrophotometer, patterns between 400 and 700 nm are the same for the natural (Bahia and Manyara) alexandrite and the synthetics produced by Kyoto Ceramics and Creative Crystals. A graph illustrates the unique differences below 400 nm, however. Kyocera alexandrite has considerable absorption in this area, while Creative alexandrite reaches a small peak at 385 nm; 355 nm is its actual peak marked by a sharp decline. This absorption pattern, similar to that found in the natural stone, results from the material's iron content. The unique absorption (at 685 nm, with a dale at 420 nm) in Kyocera alexandrite is due to its chrome content and the absence of iron.

In the X-ray fluorescence analysis, the stones on the chart were tested for chrome, iron, gallium, germanium, and platinum. Chrome was found in natural alexandrite but not in large amounts in the synthetics. Iron was found in all but the Kyocera alexandrite. In the Creative Crystal stone, iron had a very high peak, approximately 1.5 times higher than in the natural. Platinum was found in the Kyocera product because of the crucible used in its creation. The procedures detected gallium only in the naturals and germanium only in the Russian natural material. *ALS*

Computer-aided gem identification. P. Read, *Journal of Gemmology*, Vol. 17, No. 4, 1980, pp. 239–249.

Peter Read has designed table-top computer programs for a CRT (TV-type) read-out to aid in gem identification. To facilitate use of this time-saver, Read has chosen to program in tables of selected gemstones by ascending refractive indices, by alphabetical listings, and by individual "gem profiles" which list major identifying characteristics of the gemstone. When information on an unknown is put in, all possibilities in the computer's memory within a given range are suggested.

The author also discusses other types of programs that can be modified to suit a particular need. These programs appear to be very easy to read and implement. Stating that the programs were initially used as teaching aides, Read also suggests that this computer can be a valuable sales tool for retailers. *NPK*

Etude par spectroscopie raman d'inclusions dans les diamants, saphirs et emeraudes/1 (Study of inclusions in diamonds, sapphires, and emeralds by Raman spectroscopy—part 1). M. L. Dele-Dubois, P. Dhamelincourt, and H. J. Schubnel, *Revue de Gemmologie a.f.g.*, No. 63, 1980, pp. 11–14.

This is the first of a two-part article on the use of Raman spectroscopy, which permits the simultaneous identification of both the host material and its inclusions. Because it is noninvasive and not destructive, this technique is well suited for studying gems with the exception of materials that are opaque to the wavelengths of the excited photons.

With this technique, a stream of laser-generated photons penetrates the specimen, and a study of the Raman spectrum locates and identifies the different atomic constituents present therein. The beam is selected according to the inclusion in order to excite as little fluorescence as possible.

Examination of some South African diamonds identified inclusions of chrome spinel, peridot, hematite, graphite, and pyrope. A violet sapphire from Colombia contained a calcite crystal and a zircon with a tiny apatite crystal. The text is clearly illustrated with graphs of the spectra and some inclusion photographs. An excellent list of references follows the article. *CKG*

A phosphoroscope. R. M. Yu and D. Healey, *Journal of Gemmology*, Vol. 17, No. 4, 1980, pp. 250–258.

In this article, the authors explain the use of ultraviolet absorption in gem identification. The phosphoroscope allows direct observation without need of film, although film can be used if a permanent record is desired.

The specimen is placed in a simple wooden box atop a black cloth covering phosphorescent paper. An ultraviolet light (short wave) is directed on the stone and a mirror below the paper allows one to view the results through a port. In the section on observations, a rigid mathematical presentation is given to explain the cause of the dark rim seen around the edges of the stone. The type of film recommended and its use are briefly described.

Three figures are used to compare the results of testing synthetic and natural rubies, sapphires, and emeralds. The absorptive effect of iron in each material is discussed. *Chuck Fryer*

GEM LOCALITIES

The Cruzeiro mine: past and present. J. P. Cassedanne, J. O. Cassedanne, and D. A. Sauer, *Mineralogical Record,* Vol. 11, No. 6, 1980, pp. 363–370.

The Cruzeiro pegmatite mine, located northwest of Governador Valadares in Minas Gerais, Brazil, is one of the most famous gem pegmatite mines in the world. First worked for strategic mica during World War II, it has since become famous for its outstanding gem tourmalines, which are usually pink or green and may be quite large. This article is the most comprehensive to date on the Cruzeiro mine. The authors present a detailed description of the local geology and mineralogy of the deposit, with photographs and geologic maps.

The deposit consists of three elongated, subparallel pegmatite lenses, frequently only a few meters in width. The main wallrock is a white-to-light buff, medium-grained quartzite. The gem pockets appear to be localized where the pegmatites widen and are most differentiated. These widenings are frequently controlled by local arches in the hanging wall.

Currently, the mining operations are supported by independent miners working on the mica in leased areas of the deposit. However, the search for gem tourmaline continues. *Peter Keller*

First Discovery of Ruby in Australia. D. H. McColl and R. G. Warren, *Mineralogical Record,* Vol. 11, No. 6, 1980, pp. 371–375.

The first significant discovery of commercial ruby was made in the Harts Range of the Northern Territory of Australia in 1978. The ruby occurs as well-formed, hexagonal tabular crystals up to 5 cm in diameter and 1 cm thick in a distinctive layer of greenish gneiss within the Riddock amphibolite. It is thought that the amphibolite formed from a terra rossa soil profile on a limestone contaminated with pyroclastics and interlaminated with lavas and tuffs.

To date, very little material of faceting quality has been found. The Australian rubies do, however, cut pleasing cabochons. No asteriated material has been noted. The deposit appears to be extensive, with prospects good for more ruby from the Harts Range area. *Peter Keller*

New emerald mine in Itabira (in Japanese). Y. Shono, *Gemmological Review,* Vol. 2, No. 2, 1980, pp. 8–10.

With a map, some photographs, and a text based on personal observations, Yoshihiro Shono, a gemstone importer-exporter, introduces the reader to the first significant commercial-quality emerald source in the Minas Gerais region of Brazil. The new emerald site, Itabira, historically has received recognition for its aquamarine deposits, the supply of which has decreased in recent years. While the Bahia region, north of Itabira, has recorded emerald finds, no one ever anticipated an emerald occurrence in Minas Gerais. The search began in 1978, with the first significant discovery made in 1979.

According to Shono, who visited the mine, the quality of the Itabira emeralds is not inferior to the Colombian stones and is far superior to those found in Bahia. Both the color and tone are good; crystals as large as one kilo have been uncovered. Compared to the Bahia stones, the Itabira crystals have few cracks. Tubular inclusions are characteristic.

Manual mining is being conducted on 200–250 m^2 sections that are further broken down into 10 m^2 areas to which five to eight miners and one supervisor are assigned. Profits from the weekly sale of emeralds are allocated on a 20/80 ratio between owner and miners, respectively. In the near future, mechanized mining techniques will be used. *ALS*

Opal in Piaui State, Brazil. E. A. Jobbins, *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* Vol. 29, No. 1 and 2, 1980, pp. 40–54.

Geologist Jobbins describes three opal-bearing areas in the northern half of Piaui State, pinpointing sites previously known but unsubstantiated. Four types of opal deposits, each with unique mining operations, occur in the Pedro II, Castelo do Piaui, and Varzea Grande localities, but only Pedro II is economically significant. Jobbins focuses on the Pedro II area, describing first its geology and then the individual occurrences of precious opal and how they are mined. These are located on a map that includes the rivers, a major agent in the distribution of alluvial opals, as well as the quartz-dolerite dykes that functioned as feeders for quartz-dolerite sills. The author suggests that the decomposition of these sills, in providing the necessary silica, is one of five factors that may be involved in precious-opal formation at Pedro II. He also notes that while the physical characteristics of the precious opal differ considerably from one deposit to the next in the Pedro II area, the overall quality is such that there is great similarity with some of the Australian opals.

In contrast, there are no reports of precious opal in the Varzea Grande or Castelo do Piaui areas, although common opal ranging in color from clear to milky to reddish orange has been found. These areas could be explored further, but Jobbins concludes that the Boi Morto region of Pedro II is most favorable for locating new deposits. *DMD*

JEWELRY ARTS

Gold as art. B. Cartlidge, *Aurum,* Vol. 80, No. 3, 1980, pp. 4–7.

The author, a jewelry designer and freeman of the Worshipful Company of Goldsmiths, begins by summarizing what an extraordinary metal gold is and how its unique qualities have affected events throughout history. The imagery and symbolism surrounding the metal itself permeate language and transcend culture. Its stability as a metal lends toward hoarding, worshipping, and the passing of personal objects from generation to generation.

Gold is fashioned by means of a great variety of techniques and is combined with various metals to produce a broad range of colored alloys. The experience of working with gold can be frustrating to all but the most dedicated artist. Once mastered, though, it offers access to a very personal form of expression. The author lists well-known artists from around the world and describes the techniques and styles of a few. Industrial processes have made gold jewelry more available to more people but commercial production has not kept pace with contemporary design. This is due partially to the trends that commercial designers follow and partly to the concerns of manufacturers. This article offers much to the salesperson and artist alike.

RSS

Inlay techniques used in netsuke. F. Yano, *Arts of Asia,* Vol. 10, No. 5, 1980, p. 155.

This article defines and describes inlay techniques used in netsuke, beginning with the origin of inlay in netsuke and some of the schools that have used this technique. While some authorities believe inlay developed as early as the 16th century, others think it originated in the 18th century. Mr. Yano defines inlay as "the technique of combining or filling in different materials to express one's art."

The article features a photograph of Akihide Kawahara, who is described as the only living artist in Japan who has mastered both inlay and carving techniques. There are also six photographs showing the development and finished version of his kappa (water imp) netsuke, which is made of wood inlaid with tortoise shell.

In discussing the evaluation of inlay techniques, the author explains that the joining of the two materials is most important: there should be no space between them. Even if the inlay fits perfectly at the sides, there may still be a space at the bottom. Older Japanese dealers detect this by tapping the work with an ivory chopstick; if it sounds hollow, they know there is a gap at the bottom. The quality of the fit not only determines the value of the netsuke but also affects the durability of the piece.

ET

RETAILING

Promoting and merchandising coloured stones. J. Sabbagh, *Journal of Gemmology,* Vol. 17, No. 3, 1980, pp. 165–180.

Mr. Sabbagh discusses the merchandising of colored stones and covers inventory, point-of-sale merchandising, and sales techniques. The author shows himself to be a practical gemologist by suggesting ways to avoid sales-killing expressions such as "flaw," "cheap," and "cheaper." He discusses the term *semi-precious,* advising that it be discarded. This article also covers such topics as display, lighting, birthstones, skillful price tagging, and other sales techniques. Throughout the article, Mr. Sabbagh instructs gemologists to use their gemological knowledge to achieve sales priorities.

ET

SYNTHETICS AND SIMULANTS

Nuevas técnicas de observación de la luminiscencia en diamantes y en algunos de sus substitutos (New techniques for observing luminescence in diamonds and in some of their substitutes). J. M. Bosch Figueroa, L. M. Roberdeau, *Gemología,* Vol. 11, No. 43 and 44, 1979, pp. 7–12.

To compare and contrast diamonds and their substitutes, the writers devised an apparatus to expose stones to long-wave fluorescence (3650 Å) and recorded the results. The specimens selected were cut stones that exhibited phosphorescence—Cape diamonds, brown diamonds, and colorless gem materials used as diamond substitutes. The diamond substitutes emitted phosphorescence strong enough to expose photographic plates. The stones were exposed to the fluorescence for three minutes, first at 20°–25°C, then at 300°C.

Of the Cape-series diamonds, those with sharp blue phosphorescence showed more intense color at the higher temperature; those that showed blue with whitish opalescence became yellowish at 20°–25°C and intensely blue as the temperature approached 300°. The brown-series stones showed indefinite yellow and were lightly opalescent at 20°–25° C, with the color more intense at 300°. Corundum and synthetic spinels were dark red at the lower temperatures, becoming orangey red as the temperature increased. YAG and GGG were orangish at 20°–25°, turning reddish with increased temperature.

The findings lay the groundwork for the application of ultraviolet light to the further study of colored diamonds, natural and treated, as well as other gemstones.

SLD

The optical constants of G.G.G. K. Nassau, *Journal of Gemmology,* Vol. 17, No. 3, 1980, p. 148.

In this short article, Dr. Nassau gives refractive index (1.970) and dispersion (0.045) values for G.G.G. based on recent precision measurements by Dr. D. L. Wood of the Bell Telephone Laboratories.

ET

Synthesis of emerald and other colour-varieties of beryl minerals (in Japanese). I. Yagi and N. Adachi, *Journal of the Gemmological Society of Japan,* Vol. 6, No. 3, 1979, pp. 67–72.

Different from both the flux and hydrothermal methods of emerald synthesis, the newly developed gas–

solid reaction method described by authors Isao Yagi and Naosuke Adachi produces crystals that closely approximate their natural counterparts in both physical and optical properties.

The explanation of the process is purposely brief and vague because the patent is pending. Oxygen and fluorine gas react with crystalline or amorphous BeO (beryllium oxide), Al_2O_3 (aluminum oxide), SiO_2 (silicon dioxide), and doping chemicals in a platinum tube at very high temperatures. Then, at lower temperatures, crystallization occurs on seed crystals of natural beryl. To form a 1-cm crystal, this process, which takes 20–40 days, is repeated two or three times at temperatures of 800°–1000°C and gas pressure of one atmosphere.

The rate of crystallization depends on the doping agent used. By taking advantage of the differing rates of formation under controlled conditions, crystal growers can create beautiful multicolored beryl, including a watermelon variety.

Beryls produced by the gas–solid reaction method may be used to simulate a wide variety of gemstones, including morganite, aquamarine, almandine garnet, blue spinel, amethyst, jade, peridot, turquoise, amazonite, rubellite, rose quartz, and others. The ASIC (synthetic) emerald closely resembles the natural in appearance and properties and is discussed most completely in the article.

In addition to photographs, the authors provide charts of optical and physical properties for various doping materials. The exact doping agents for the ASIC emerald are not given, but its characteristics are as follows: color, green; Munsell color standard, 5G ¾; dichroism, strong blue green to yellow green; spectrum, absorption above 7000 Å and at 6900 Å, weak at 5900 Å and below 4200 Å; fluorescence, light red under both long- and short-wave ultraviolet light; average refractive index, 1.570; specific gravity, 2.67. X-ray diffraction patterns are also noted for the ASIC emerald and for other doping agents.

While the authors claim success, they also acknowledge the need to improve the technique, especially with respect to speed and the transparency of the end product. *ALS*

Synthetic amethyst: its history, methods of growing, morphology and peculiar features. V. S. Balitsky, *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 29, No. 1 and 2, 1980, pp. 5–15.

Balitsky discusses the evolution of the basic methods of growing synthetic amethyst while highlighting their characteristics and their differences. The first method used the hydrothermal process with a strong alkali-aqueous solution as a solvent. Iron is incorporated as a structural inclusion which produces the amethyst color when irradiated. The smoky coloring, which devaluates the stones, can be held to a minimum by using charge quartz of high purity or adding oxidizers such as lithium nitrite. Crystals grown by this method usually have a flattish shape with hillocks composed of Brazilian twins on the positive rhombohedral faces and dophinean (sic) twins on the negative rhombohedral faces.

The second method of growing synthetic amethyst crystals also used the hydrothermal process but with aqueous solutions of ammonium fluoride as the solvent. With this solvent, the aluminum-alkaline centers of smoky coloring are eliminated. For crystals of the best color throughout the growth layer, alkaline metal ions such as those of lithium are added. This protects the amethyst color centers from thermal destruction while in the autoclave. The external morphology differs from that of the material produced by the first method in that it has growth pyramids instead of twins on the crystal surfaces.

The spectra of the synthetic amethysts have the same approximate absorption bands as natural amethyst, although the alkaline-produced stones match the spectra of the natural material more closely than do the fluoride-produced stones. As helpful as the text, nine figures, and bibliography are, the reader is advised that the article has been roughly translated and will require extra effort to read. *GSH*

MISCELLANEOUS

Les joyaux de la couronne de France à la veille de la revolution (The French crown jewels on the eve of the revolution). B. Morel, *Revue de Gemmologie a.f.g.*, No. 63, 1980, pp. 2–8.

The author begins with an account of how the jewels belonging to the French royalty were inventoried and appraisals made according to decrees of the National Assembly in May and June 1791, on the eve of the French Revolution. He explains how diamonds were evaluated during that period, and points out the differences between the old carat (0.205 g) and the metric carat (0.200 g) as well as interpreting currency equivalents in modern francs.

The historic detail may be of interest, since some well-known stones are mentioned. However, the article is primarily a catalog of all the royal jewels: not only diamonds, but also unmounted pearls, rubies, topazes, and emeralds. It includes six well-captioned, black-and-white photographs and sketches and a short bibliography citing several catalog and historical references. *CKG*

GEM NEWS

Stephanie Dillon, *Editor*

AFGHANISTAN SITUATION

Reports from a neutral observer are that Afghanistan's gem-yielding districts, in mountainous terrain, have not fallen to the Russians.

Sar-El-Sang, in the province of Badakhshan, is the prime source of lapis lazuli, and the Nurestan pegmatite district produces beryls, tourmalines, and kunzite. Prior to the Russian incursion, about a ton of lapis was exported per year. Although mining has virtually halted, it appears that material continues to leave the country, thanks to the considerable reserves existing at the time of the invasion.

DIAMONDS

Australia. Since 1978, exploration in Western Australia's Kimberley region has been pursued by numerous groups on over 5,700 claims of 120 hectares (296.4 acres) each. Samples from one of 28 kimberlite pipes in Ellendale Province have yielded approximately one carat per 22⅓ tons of material, with close to 18,000 stones taken thus far from the region. The largest piece of rough was 6.47 carats; the average weight was 10 points. It is thought that these sources will produce a high percentage of gem-quality stones.

More excitement has been generated over primarily industrial-quality finds near Lake Argyle, close to the Northern Territory border. Eight hundred carats of diamonds per 100 tons of associated alluvial gravels have been recovered as far as 20 miles from the pipe itself. The pipe covers 111 acres at the surface, making it one of the world's largest. More than 5,000 carats have been produced, with the largest stone weighing 7.03 carats. The treatment plant has been relocated here from Ellendale. It will have the capacity to process up to 3,000,000 carats per year from the upper alluvial deposits.

India. A countrywide exploration project was announced last April, following the geologic find of potentially workable deposits.

India's diamond-cutting shops number around 20,000 and employ 300,000 cutters and polishers. In addition, there are more than 1,500 registered exporters. Obtaining sufficient rough has been a problem: India's sole mining operation at Panna supplies only 0.001% of the 18 million carats used annually, and the amount purchased from De Beers is less than satisfactory. Expanding domestic production to 100,000 carats a year is an industry goal. Also in process are plans to purchase rough directly from Ghana, the world's fifth largest diamond producer.

China. Last September, a year-long Sino-German trade agreement, whereby German training and technology are combined with Chinese labor and diamonds, culminated in the opening of Peking's first diamond-cutting factory. The Peking Jewellery branch of China's National Arts and Crafts and Industrial Products Company received the key to the factory from V.K. Narasimhan, of Frankfurt. The same day, the diamond-cutting school, established by the German company for 50 students in January of 1980, was donated to the Chinese authorities.

More diamond-cutting schools and factories are to be established. China reportedly plans to employ 300,000 people in the cutting of diamonds by 1985.

Diamonds are mined in Hunan province both from a huge source discovered in the 1960s and from a pipe recently found in Liaoning. Estimates are that 1.8 to 2.8 million carats are being produced, with some American advisers assisting in the renovation of the mines. The Chinese plan to market their diamond exports through Frankfurt rather than De Beers.

U.S.A. The Wyoming Geological Survey is extending to a second year the completion of its report on diamond deposits in kimberlitic pipes and placer traps in the Laramie and Snowy ranges. Undertaken by the Mining and Mineral Resources Institute of the University of Wyoming for the U.S. Department of the Interior, the study has turned up two new kimberlites as a result of the stream-sediment samples collected last summer.

U.S.S.R.—Record Stone. In December, the discovery of the largest diamond yet found in the Soviet Union was reported. According to Tass, the Soviet news agency, it is egg-shaped, lemon-yellow, transparent, and weighs 342.5 carats, 110 more than the previous record-holder, the Star of Yakutia. It was also found in the Yakutia region of northeastern Russia.

RUBY

While much of the material from Kenya is brownish and suitable only for cabochons, the gemstone belt from the Taiti Hills to the Tanzania border has been found to contain deposits of fine, Burmese-color rubies of up to one carat. No real mining activity has occurred as yet.

A large ruby field in Australia's Harts Range, northeast of Alice Springs in the Northern Territory, has yielded approximately 40,000 carats in cut stones in the past year and a half. Since most of the material is not of high quality, the find does not affect the current shortage of finer stones.

A recently discovered ruby deposit in Mysore state, southern India, has produced stones of fine color but suitable only for spheres and cabochons.

The Hunza Valley of northeastern Pakistan is a 30-square-mile area containing deposits of various gems, but it is particularly rich in ruby. From July 1977 to June 1978, 42.2 million carats of rubies were recovered there. A government corporation mines, cuts, polishes, and markets the stones. While much of the material is considered excessively flawed, some specimens that have appeared in the U.S. indicate that stones of excellent quality may be forthcoming.

SAPPHIRES

Kashmir, India, sapphire production, halted in recent years, may be resumed on the recommendation of the board of directors of state-owned Jammu and Kashmir Minerals Ltd. The plan to lease out the Paddar Sapphire Mines was made by the state in 1977. The leasehold of JKM is due to expire in 1982; a new lease order must be approved by the Indian government. Four firms are bidding for a 20-year lease, offering plans for mine development and establishment of a state gem-cutting and polishing industry.

A sapphire deposit in North Queensland, Australia, has yielded stones of up to 10 carats.

SRI LANKA LAPIDARY

The Greater Colombo Economic Commission of Sri Lanka has signed an agreement with a Monte Carlo gem and jewelry dealer to establish a gem-cutting enterprise in the coastal town of Kalutara, 16 miles south of Colombo. About 400 people will be employed on the five-acre site to work with locally available gemstones and imported diamonds, colored stones, gold, and silver, which will be marketed chiefly in Japan, North America, and Europe.

TUCSON GEM AND MINERAL SHOW ACTIVITY

Aquamarine. Aquamarine from mountainous Boise County, Idaho, attracted considerable interest. Aquas have been mined in the area for about two years. Each pocket produces approximately a half-kilo of crystals. The rough has yielded cut stones of up to seven carats of excellent, medium color.

Red Beryl. From a total production over the last year of 1,000 carats of red beryl from the Wah-Wah Mountains of Utah, about 500 carats were on display in Tucson. The majority of the yield has been stones of from 10 points to one-half carat, the largest fine-quality stones weighing about one and one-half carats.

Synthetic Red Beryl. While its emeralds are showing fine color, Regency Created Emeralds Company, in its attempt to produce red beryl through the hydrothermal process using manganese as a coloring agent, has so far produced only pink beryl.

Sugilite—A New Gem Material. "Royal lavulite," referring to the sugilite accidentally discovered in last year's roof collapse of a South African manganese mine, was prominent in Tucson. Of the probable three tons in the deposit, 360 kg are suitable for jewelry, about 18 kg of which show extraordinary color—blue-purple to red-purple to magenta.

Pink Fluorite. Of special interest to mineral collectors were samples of pink fluorite from a December find in Huanzala, Peru. About 500 matrix pieces with octahedral crystals were discovered.

The color does not fade in sunlight, but rather intensifies after several days' exposure. The crystals, unusual for their color as well as for their sharply octahedral shape (most fluorite is cubic), are up to 40 mm in size, some clear enough for faceting. The crystals show a rich pink color in daylight, with green centers; under fluorescence and incandescence, the colors become dim.

Topaz. Topaz was another stone in great abundance at the show. However, the recent closing of two Ouro Preto mines, combined with the approach of the rainy season (when mine activity generally slows or halts), may soon be reflected in a topaz shortage.

EXHIBITS

Carnegie Institute's Museum of Natural History—4400 Forbes Ave., Pittsburgh, PA 15213. Telephone: (412) 622-3269.
The Hillman Hall of Gems opened in September 1980, and contains a collection of over 2500 gems and minerals.

Denver Museum of Natural History—City Park, Denver, CO 80205. Telephone: (303) 575-3923.
A gem hall is under construction to be opened this fall. It will occupy an alcove off the museum's new mineral hall and will present all new donations and exhibits from the museum's collection. There will be about ten displays of gems from around the world, including a 10,599-carat Brazilian topaz that was part of an artistic project created by Salvador Dali. A special collection of Colorado gemstones will include approximately 30 specimens.

Lizzadro Museum of Lapidary Art—220 Cottage Hill, Wilder Park, Elmhurst, IL 60126. Telephone: (312) 833-1616.
The Lizzadro is a public museum displaying gems, minerals, and art objects made of gem materials; there is a large collection of carved jades and numerous mineral specimens. Earth science lectures are presented each Saturday afternoon at 2:00. On Sundays, there are gem-cutting demonstrations via closed circuit television.

Los Angeles County Museum of Natural History—900 Exposition Blvd., Los Angeles, CA 90007. Telephone: 744-3328.
"Sweat of the Sun, Tears of the Moon" is the largest exhibit of Colombian gold artifacts and rough and cut emeralds ever to be exhibited outside of the Republic of Columbia. Opens July 4 and continues through September 6, 1981.

ANNOUNCEMENTS

The Adele Steacy Memorial Scholarship is offered annually and is open to a resident of Brockville, Ontario, needing aid to study gemology. The scholarship provides up to $2,500 for the recipient, who will seek employment in the Canadian jewelry industry upon the completion of his studies, to attend GIA or its equivalent in Canada. Should no application be made by a Brockville resident, other residents of Ontario will be considered. Applications may be submitted to the Assistant Registrar (Student Awards), Queen's University, Kingston, Ontario K7L 3N6, prior to July 1.

At a meeting held February 12 in Tucson, Arizona, formation of a new organization, the **American Gem Trade Association, Inc.**, was announced. The object of AGTA is to promote the interests of colored stone dealers while establishing a code of ethics for the industry. Information can be obtained from Treasurer David Nassini, of American-Ariana Trading Company, 2 West 46th St., New York, NY 10036.

Gems & Gemology welcomes news of exhibits and events of a gemological nature. Please contact Stephanie Dillon, Gemological Institute of America, 1660 Stewart St., Santa Monica, 90404. Telephone: (213) 829-2991.

BOOK REVIEWS

John I. Koivula, Editor

AMBER: THE GOLDEN GEM OF THE AGES

By Patty C. Rice, 289 pp., illus., Van Nostrand Reinhold Co., New York, 1980. $26.95

As Dr. Rice indicates in her preface, the intent of this book is to enlighten people on all aspects of amber, including its history, lore, science, and modern sources. After an introduction (part 1) that touches on amber both as a gemstone and as a fossil resin, the human aspects of amber are presented in part 2, beginning with its earliest occurrences in the archaeological record. Of particular interest to some will be the description of the early trade routes in Europe as derived from finds of amber artifacts. Within this section, the organization of the amber guilds and the historical methods of collecting amber are described, as are the amber centers of the USSR and Europe. Finally, no book on amber would be complete without the chapter on lore that follows.

Part 3 comprises the largest section of the book, with four chapters on the more scientific aspects of the golden gem, from its physical properties through the geologic theories of its origin and finally to a description of the other natural resins that are similar to amber. The final section, "Commercial Aspects," includes a chapter on amber imitations and how to distinguish them; the chart of their characteristics will be helpful to the gemologist.

A major asset of this book is the use of so much information from Eastern Europe and the Soviet Union. There are also references at the end of every chapter and an extensive bibliography at the conclusion of the work. Many unusual specimens and jewelry pieces are included in the photographs, but one wishes that more care had been taken to show their uniqueness. Another suggestion for subsequent editions of the book would be to include a table of illustrations.

Amber: The Golden Gem of the Ages will be enjoyable and useful for the casual reader as well as for the gemologist interested in refining his or her knowledge of amber.

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OPTICAL MINERALOGY
The Nonopaque Minerals

By Wm. Revell Phillips and Dana T. Griffen, 677 pp., illus., W. H. Freeman & Co., San Francisco, CA, 1981. $39.95

Wm. Revell Phillips's earlier work, *Mineral Optics: Principles and Techniques*, has become a popular college-level text covering the basic principles of optical mineralogy. Missing from that book, however, are the tables of optical constants and mineral descriptions that are generally included in such texts. Phillips, together with Dana T. Griffen, conceived *Optical Mineralogy: The Nonopaque Minerals* as a companion volume to provide the important optical data. From this original concept, however, grew their ambitious attempt to compile "a truly comprehensive summary of the optical properties of minerals." In this attempt they have been remarkably successful. Their work ably replaces earlier, out-of-date standard references in the field. Although the book is intended primarily for mineralogists and petrologists, workers in related fields, including gemology, are likely to find it of value.

The book is divided into two parts. The first 398 pages contain detailed descriptions of 159 of the more common rock-forming minerals or mineral series. The descriptions are clear and concise. The optical data provided are complete for most mineralogical applications. Additional information provided includes atomic structure, chemical composition, physical properties, crystal form, and occurrence. Illustrations, where appropriate, show the atomic structure, the orientation of optical directions relative to crystal habit, the variation of optical properties with composition, and the appearance of the mineral in thin section. Of particular value to researchers is the list of references that follows each description.

Part II consists of 267 pages in which the optical and physical properties of all nonopaque minerals, including those described in part I, are summarized. The minerals are grouped according to optical character and are listed in order of increasing refractive index. This method of arrangement facilitates optical identification. It is part II that gives this book its singular importance, for nowhere else does such an up-to-date compilation exist.

In its planning, arrangement, content, editing, and printing, this is a first-class publication. It is not without minor errors (i.e., mineralogy is misspelled in the first line of the preface), but these are easily disregarded. This work should quickly be accepted as a standard reference by mineralogists and petrologists. As such, it is well worth its price of $39.95; however, this price may discourage its use as a supplementary college text.

The book's value as a gemological reference must be considered somewhat limited. Not all of the diagnostic optical properties used by gemologists are included (i.e., absorption spectra, fluorescence), important gem varieties are not stressed and in some cases are not even mentioned, and the terminology and explanations are not gemologically oriented. Nevertheless, for gemologists with mineralogy backgrounds, those working with unusual gemstones or rough gem materials, and those using mineralogical techniques, this reference will prove particularly useful.

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